Highlights

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INTRODUCTION

This publication has been compiled from two reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space, and covers the period from 1 November 1994 through 31 October 1995. The first part of the report, on space technology, applications, international cooperation and space law, was prepared by the International Astronautical Federation (IAF). The International Institute of Space Law (IISL) provided input for the section on space law. The second part, which focuses on space science, was prepared by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Many of the most prominent international experts from many countries have contributed to this comprehensive and authoritative survey. The infomation it contains reflects the wide range of space activities currently being conducted in many national and international space programmes. A list of contributors is located at the end of the report. This publication is being circulated only in the language in which the reports were prepared and submitted.

This review of recent developments in space science, technology, applications, international cooperation and space law is intended to provide information on these developments to a broad international audience. First published in 1992 as part of United Nations activities undertaken for International Space Year, the publication seeks to increase the awareness of all countries of the benefit of space activities.

It is hoped that this publication will make a significant contribution to the ongoing United Nations effort to disseminate information on space activities and to highlight the benefits they provide to all countries of the world.

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PART ONE:

HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS, 1995

I. OVERVIEW

1995 will go down in space history as the year in which the world's major spacefaring nations took the first step in the long-term development of space as a truly cooperative venture for humanity. The linkup of the United States Shuttle Atlantis with the Russian Federation's Mir space station, unlike the previous Apollo-Soyuz mission in 1975, was not just a symbolic one-time gesture toward peace. As the first of a series of Shuttle-Mir missions leading to the deployment and operation of a truly global space station, it opened a new era of international partnership in space development and exploration. This year, therefore, ranks with 1957, when the world's first spacecraft orbited the Earth, and 1969, when a human being first walked on a non-terrestrial surface, as the third rung in humanity's ladder to the stars.

The Shuttle-Mir rendezvous and docking on 29 June also demonstrated that systems developed by different nations having very different technical standards and operational procedures can work together smoothly and effectively, easing one of the major concerns that had been expressed about the deployment, assembly, and operation of an international space station. Alleviation of this concern, along with the resolution of programmatic issues in the United States, the Russian Federation, Europe, and Canada, made 1995 the year in which the International Space Station Alpha finally appeared to be on track after a decade of vacillation (Japan has been firmly committed from the inception of the international space station effort).

The trend reported last year toward consolidation, joint ventures, and international interaction in commercial space ventures continued to strengthen in 1995. This year's bell-wether events included the first contracts to provide western hardware for a Russian launcher, payload adapters built by Sweden's Saab Ericsson Space; the first Russian launch of a United States commercial satellite, the orbiting of FAISAT-1 by a Cosmos launched from Plesetsk; the first non-Ariane launch commitment by an Ariane contractor, Daimler Benz's contract for a Long March launch of the Argentine Nahuel satellite; the first leasing of capacity by the International Telecommunications Satellite Organization (Intelsat) from a non-Intelsat spacecraft, India's Insat 2E; China's first order for a 100 per cent Chinese-owned, Chinese-operated commercial satellite system, ChinaStar-1, to be built by Lockheed Martin; the first merger of second-tier space companies across national boundaries, Saab Ericsson Space with two small Austrian companies; the first Russian rocket engines to be shipped to the United States for potential use on United States launch vehicles; creation of the Skyways Alliance for communications with aircraft by organizations in eight nations; and establishment of a joint mobile satellite communication service, the Association of South East Asian Nations Cellular Satellite System (ACES), by companies representing the six countries of the Association of South East Asian Nations (ASEAN).

Prototype services were begun this year by the first of many planned mobile communications systems using hand-held ground terminals: American Mobile Satellite Corporation's geostationary-orbit (GEO) MSAT and Orbital Sciences Corporation's first two low Earth orbit (LEO) Orbcomms. The latter represent the major trend toward small satellite systems that was reported last year, a trend that is becoming even stronger for scientific and space exploration satellites than for commercial ones because of ever-increasing pressures on government budgets. This year, the United States National Aeronautics and Space Administration (NASA), for example, awarded the first contract in its low-cost, low-mass Discovery series, the Lockheed Martin Lunar Prospector, which will carry five sensors to study the composition of the Moon from low orbit for only $59 million. In Europe, the European Space Agency (ESA) funded studies for a Small Missions Opportunity Initiative aimed at creating a commercial consortium to build and launch small satellites. NASA took by far the biggest step toward spacecraft miniaturization this year by announcing its plan (including first-year funding) for a New Millennium programme aimed at using new technologies to achieve order-of-magnitude reductions in the size and cost of spacecraft for science and exploration while at the same time increasing their performance and capabilities. The first contract in this new series went to Spectrum Astro for a flight to comet Faye and two asteroids.

The market for large commercial satellites, however, continued to proliferate, with 15 applications filed by both large and small corporations in time to meet the 29 September deadline set by the United States Federal Communications Commission (FCC) for proposals on new high-frequency (Ka-band) communication systems. The accelerating growth of commercial market opportunities this year appears to have reversed last year's apparent surfeit of space transportation service providers and analysts now project a growing shortage of launchers during the coming decade.

In space transportation itself, however, the news was both good and bad. For the first time in decades, the United States initiated what appear to be budgetarily realistic programmes both to make major improvements in current launch vehicles and to demonstrate the technologies needed for low-cost reusable next-generation launchers. Key projects begun by the United States this year were the X-33 Advanced Technology Demonstrator, the X-34 small orbital launcher, the MedLite and Ultralite procurements, and the Evolved Expendable Launch Vehicle. However, a rash of launch failures in 1995 created major concerns about the maturity of global space efforts. These included not only new vehicles such as the United States Astria (formerly the Lockheed Launch Vehicle), Pegasus XL, EER's Conestoga, and the Russian Start-1 and Rockot, but also old reliable systems: Europe's Ariane-4, the United States Delta, Japan's M-3S2, and China's Long March 2E. Other vehicles experienced problems that delayed launches, some for extended periods: the United States Titan-4 and the Shuttle, Japan's H-2, and Europe's Ariane-5. Both national space agencies and customers for commercial launches, as well as the insurance industry, are pressing launch-vehicle developers and launch service providers to demonstrate an early return to reliable operations in 1996.

II. SPACE TRANSPORTATION

A. Current Launch Activities

NASA released its request for proposals for the Med-Lite launcher on 5 December 1994, and on 24 March selected the team of McDonnell Douglas Aerospace and Orbital Sciences Corporation (OSC) to provide launch services. The only other bidder was Polyot Astro Satellite Systems Ltd., a joint United States-Russian venture, which offered the Russian Cosmos launcher. Plans for Med-Lite launches include the Far Ultraviolet Explorer in October 1998 and Mars exploration spacecraft in December 1998 and January 1999. The contract calls for these three and two more firm launches, plus nine options for additional Med-Lite launches. The team plans to use OSC's Taurus vehicle to launch payloads of up to about 1,400 kg to LEO, and to develop a new three-stage Delta-Lite for payloads in the 1,900-2,540 kg range. Delta-Lite would use solid-propellant Thiokol Castor 120 rockets for its first two stages and a third stage based on current Delta-2 upper-stage elements.

NASA also issued a contract to OSC in December 1994 for "Ultralite" launch services. Other bidders were PacAstro and Space Vector. The contract calls for two firm launches of Pegasus XL vehicles and up to eight options. Average cost per launch of payloads up to 140 kg into 480-km orbits is $6.7 million. Maximum payload length is 1.8 m. However, the second failure of a Pegasus XL during a 22 June launch attempt, in which a 265 kg United States Air Force Space Test Experiments Platform (STEP-3) was lost, spurred NASA to begin seeking other alternatives to launch its growing backlog of small science missions. The Pegasus XL failure was apparently caused by the incomplete separation of the second stage from the interstage adapter, which was attributed to improper installation of a skid between the first and second stages.

The first two Atlas launchers to be flown by the newly merged Lockheed Martin company were launched only two days apart, on 22 and 24 March. The first was the Atlas 2AS, which orbited its third Intelsat 705 from Cape Canaveral; the second was the last Atlas-E, built 34 years ago. It was launched from Vandenburg Air Force Base in California, placing a Defense Meteorological Satellite Program (DMSP) spacecraft into a polar orbit.

CTA Inc., of the United States selected the Lockheed Launch Vehicle (LLV), renamed Astria in September 1995, to launch its Clark satellite, the second of NASA's Small Spacecraft Technology Initiative (SSTI) projects. The launch contract was signed 1 December 1994, following TRW's earlier choice of the LLV for Lewis, the other SSTI spacecraft. Unfortunately, however, during the LLV's much-delayed first flight on 15

August, the vehicle pitched out of control and had to be destroyed shortly after ignition of the second stage, when the vehicle had reached an altitude of about 165 km. The large oscillations started about 79 seconds into the flight, and continued after first-stage burnout of the Castor-120 rocket at 91 seconds. The second stage ignited about 5 seconds early, at 150 seconds, but continuing severe vehicle oscillations necessitated destruction of the vehicle by the range safety officer at 160 seconds. The lost payload was a GEMstar-1 data communications satellite built by CTA for Volunteers in Technical Assistance (see below). Astrias have also been selected to launch NASA's Lunar Prospector in June 1997 (the first Astria-2 flight), two remote-sensing satellites for Space Imaging Inc. in 1997 and 1998 (see below), and Taiwan's ROCSat-1 in mid-1998.

The countdown for EER Systems' (United States) new Conestoga launcher began on 13 August but was stopped 98 seconds prior to liftoff due to hydraulic-system pressure loss in the thrust vector control actuator of two of the vehicle's four Castor-4B solid-propellant boosters. Conestoga's first payload was to be the Meteor recoverable capsule originally developed under NASA's COMET program for microgravity research (see below). However, Conestoga's second launch attempt ended in failure on 24 October, when the rocket exploded shortly after being launched from Wallops Island, Virginia.

Ariane's third-stage gas generator failed to deliver full power during a launch on 1 December 1994, dropping the 2,985-kg PanAmSat-3 satellite into the Atlantic Ocean after reaching an altitude of about 200 km. This was the first failure of the gas generator, which delivered only 70 per cent of its rated power. It had no relation to the previous Ariane failure on 24 January 1994, which had been traced to overheating of the third-stage turbopump. The 1 December launch was the first to use an upgraded third-stage engine, with 700 kg more propellant than previous models. The upgrade did not affect the failure of the gas generator, which was subsequently identified as having been caused by a process-control problem.

Ariane returned to service on 28 March with the launch of Ariane-71, a 44LP configuration, which orbited Embratel's Brasilsat B2 and the European Telecommunication Satellite Organization's (Eutelsat) Hot Bird-1. Brasilsat B2 has one X-band and 28 C-band transponders to provide South America with television, telephone, and data services. Hot Bird-1's 16 Ku-band transponders transmit direct-to-home television via 70-cm receiving antennas in Europe and the Mediterranean countries. It went into service at 13 degrees east longitude on 29 April.

On 24 October 1994, the first contracts to provide western hardware for a Russian launcher were signed by Sweden's Saab Ericsson Space. The company delivered three payload adapters for 1996 Proton launches of three western satellites; Inmarsat-3, a satellite owned by Space Systems Loral (United States), and one owned by Société Européenne des Satellites (SeS/Astra, Luxembourg). The $4.5 million contract with Lockheed-Khrunichev-Energia International (later renamed International Launch Services) for the three units also included options for up to seven additional adapters.

The first Russian launch of a United States commercial satellite occurred on 24 January, when a Cosmos launched from Plesetsk orbited a store-and-forward communications satellite, FAISAT-1, owned by Final Analysis of the United States. The same launch carried Astrid-1, a 28 kg scientific satellite owned by Swedish Space Corporation (SSC), into a 1,000 km orbit, along with a Russian Cosmos 3M maritime navigation satellite. Astrid's power supply failed about five weeks later on the satellite's 494th orbit, shutting down all three of its instruments, but SSC claims that most of the desired scientific data had already been obtained. The total cost of the Astrid program was $800,000.

Polyot Experimental Design Bureau (Russia) and Assured Space Access (United States) signed an agreement on 20 September creating the joint venture, Cosmos United States, to market the Cosmos launcher in the United States. However, Final Analysis (United States) has reserved 10 Cosmos launchers and also has separate arrangements with Polyot to market them in the United States. Cosmos is a small two-stage vehicle used for both suborbital and orbital payloads. It can launch 1100-1400 kg to low (400 km) orbit, and has a failure rate of 3.8 per cent in 411 orbital launches. It has also been used for over 300 suborbital launches.

On 29 September, the United States Department of State approved the first export license for a United States satellite launch by a converted Russian ballistic missile: EarthWatch's Earlybird commercial remote sensing satellite aboard Start-1 in 1996 (see below). The new United States policy stipulates a case-by-case review of each United States application for a converted Russian ballistic missile launch.

Khrunichev State Research and Production Space Center (Russia) and Daimler Benz Aerospace (Germany) signed an agreement in March creating a joint venture, Eurockot. This formalized a prior agreement to market commercial launch services using the three-stage Russian Rockot, an SS-19 ballistic missile derivative which has been successfully flown three times. The new company, Eurockot Launch Services GmbH, hopes to launch three payloads annually from Plesetsk beginning in 1997, increasing to six annually by 1999. Rockot's payload capability, with a new Khrunichev "Breeze" upper stage, ranges from 250 to 1,800 kg into LEO from Plesetsk.

On 4 May NPO Yushnoye (Ukraine), Energiya (Russia), Kvaerner A.S. (Norway), and Boeing Commercial Space Company (United States) signed an agreement establishing a new joint venture, Sea Launch, to provide commercial launch services using Ukrainian Zenit vehicles launched from a converted oil rig that would be towed to an equatorial site in the Pacific Ocean. Boeing will be the system integrator; Yushnoye will provide the launcher, Energiya will supply the upper stage needed to give the Zenit geostationary-orbit capability; and Kvaerner will convert the oil rig to a launch platform and build a new 31 tonne, 200 m ship to tow the launch platform and serve as the launch control center. The total investment for the system is estimated at $400-$500 million, with the first launch tentatively scheduled for 1998.

A five-stage version of the Russian Start-1, derived from the SS-25 missile, failed after launch from Plesetsk on 28 March, destroying its three payloads: Israel's Techsat Gurwin-1, a Mexican communications satellite, and a Russian prototype satellite. The only previous Start-1 launch, a four-stage version launched from a mobile platform in 1993, had been successful. The $3.5-million Gurwin-1, built at Israel's Technion Institute of Technology, was to have conducted tests of remote sensing, communications, and science projects. Israel announced on 1 June its intent to build and fly a replacement.

On 6 May, Space Systems/Loral (United States) selected the NPO Yushnoye Zenit-2 (Ukraine) to launch 36 of the company's planned 56 Globalstar LEO satellites (48 operational and 8 spares) in 1998. The three launches, each carrying 12 satellites, will be conducted from Baikonur Cosmodrome in Kazakhstan. The first four Globalstar spacecraft were contracted on 20 March to be launched by a United States Delta-2 in 1997, along with options for 10 additional launches of four spacecraft each. In June, Space Systems/Loral finalized its 1993 agreement with China's Great Wall Industry Corporation for two Long March launches by contracting for one launch of a modified Long March 2E, the Long March 2E/TS, to orbit 12 Globalstar satellites in 1998 and a second to launch a Space Systems/Loral geostationary satellite purchased by the Mabuhay Philippine Satellite Corporation. Space Systems/Loral also reserved a third Long March for a future launch of either another GEO spacecraft or a 12 satellite Globalstar payload if one of the earlier launches fails.

Ukraine conducted its first commercial launch on 31 August, when a Yushnoye Design Bureau Tsyklon rocket from the Plesetsk Cosmodrome (in Russia) orbited two remote sensing satellites: the 1900 kg Yushnoye (Ukraine) Sich-1 side-looking radar spacecraft (formerly known as "Okean") and the Chilean Air Force's 50 kg FASat-Alpha (see below). The Tsyklon has been launched 118 times since June 1977 and has achieved a 3.4 per cent failure rate.

The launch of a Gorizont communications satellite by a Proton vehicle on 31 August marked the 3,000th orbital launch from the Baikonur Cosmodrome, starting with Sputnik-1 in October 1957. The 3,001st launch followed on 3 September, when a Soyuz launch carried three cosmonauts to Mir.

China's Long March 3A delivered a 2.2 tonne DFH-3 communications satellite to GEO on 30 November 1994. The 24-transponder (C-band) spacecraft was built jointly by the China Academy of Space Technology and Deutche Aerospace. The satellite unfortunately failed after five weeks in orbit, probably due to a propellant leak in the on board propulsion system. The LM-3A's first flight, carrying a dummy payload, had been in February 1994. Its payload capacity to GEO is about 2.3 tonnes. A Long March 2E failed to deliver Apstar-2 to orbit on 26 January (see below) when high winds aloft and wind shear caused the launcher and payload to break up and explode.

A new trade agreement between China and the United States was signed on 27 January. It allows China's Great Wall Industries to launch up to 15 geostationary satellites through 2001, including the four already under contract as of that date, at prices no lower than 15 per cent below those charged by United States commercial launch service providers. The previous agreement, which expired on 31 December 1994, had specified nine launches over six years at prices comparable to those of United States companies. The new agreement also covers low-orbit launches, stipulating that Chinese prices must be on par with United States launch prices. It allows the number of Chinese GEO launches to increase beyond 15 if the annual average of all geostationary launches exceeds 20 or if United States launchers cannot meet the demand. Officials from the United States and Russia plan to meet by the end of the year to renegotiate their current launch-service trade agreement.

On 5 May Daimler Benz (Germany) signed a contract with the China Great Wall Industry Corporation for a Chinese Long March 3C to launch the second Argentine Nahuel satellite, the first of which is being built by a team of Daimler Benz, Aerospatiale (France) and Alenia Spazio (Italy) for launch aboard Ariane late next year. This is the first time an Ariane contractor has elected not to launch on Ariane. Daimler Benz builds the Ariane-4 second stage and the vehicle's liquid-propellant boosters.

On 18 March, after several delays due to technical problems with the 3.6 tonne Space Flyer Unit (SFU), Japan's H-2 finally launched the $470 million SFU and the 756 kg Geostationary Meteorological Satellite (GMS-5).

Israel launched its third Ofeq satellite aboard the three-stage all-solid-propellant Shavit on 5 April. The westward launch over the Mediterranean from Israel's Palmachim missile base placed the 225 kg satellite in a retrograde 300 x 700-km orbit inclined at 37 degrees to the equator. Unlike its two predecessors, Ofeq-3 is three-axis-stabilized and is able to be maneuvered in space from the ground.

B. Development Activity

On 1 March the United States Air Force issued a draft request for proposals (RFP) on an Evolved Expendable Launch Vehicle (EELV) to cover and extend the payload range currently met by Delta, Atlas, and Titan launchers (1,125-20,250 kg into LEO). The final RFP was issued on 17 May, and proposals were received by the Air Force on 16 June. Fifteen-month Phase-1 risk-reduction contracts totalling $120 million were announced on 15 September to Lockheed Martin, McDonnell Douglas, Boeing Defense and Space Group, and Alliant Techsystems. After this phase, 17-month Phase-2 contracts will be awarded to two companies or teams with a down-select to a single contractor planned for full-scale development. Total programme cost is estimated to be $1.5 billion. The first medium-lift vehicle is scheduled for launch in 2000; the first heavy-lift launch will be in 2003. The EELV development implements United States President Clinton's 4 August 1994 space launch policy statement, which gave the Department of Defense (DOD) responsibility for incremental improvements to current United States launch capabilities. It also incorporates a May 1995 DOD policy on the use of Russian engines (see below), which requires that the United States vehicle contractor take over production of any Russian components within 4 years after the DOD production contract award.

Although vehicle designs of the four EELV contractors are not yet firm, they have announced their preliminary plans. McDonnell Douglas expects to use Delta-2 and Delta-3 upper stages with a booster powered by a yet to be selected engine (see below). Boeing's plans are focused on its Inertial Upper Stage with a vehicle core using recoverable Space Shuttle Main Engines and a range of solid-propellant booster motors such as Thiokol's Castor-120 and Castor-170. Lockheed Martin is likely to use an upgrade of its existing Centaur upper stage, with a new booster core powered either by Russian engines (see below) or an upgraded Rocketdyne engine, with similar strap-on (liquid-propellant) boosters for heavy-lift missions. Alliant Techsystems will use the company's Solid Rocket Motor Upgrade, developed for the Titan-4, and Ariane-5's cryogenic core.

The DC-X flight-test program, interrupted last year by damage incurred due to an external explosion on 27 June 1994, resumed on 16 May. Further flight tests in 1995 were conducted at the White Sands Missile Range under the cognizance of the United States Air Force Phillips Laboratory on 16 May, 12 June, and 7 July. They demonstrated increasing angle of attack pitchover maneuvers ranging up to the 180 degrees which would be required of an operational vehicle. An additional flight, which was to have been made within 72 hours after the last one on 7 July to demonstrate rapid turnaround capability, was cancelled due to minor damage resulting from too rapid a descent during the 7 July flight. McDonnell Douglas then began conversion of the DC-X to the DC-XA, which will be used by NASA to demonstrate key technologies for the X-33 programme (see below). The conversion includes replacing the aluminum propellant tanks: the hydrogen tank with one built from composite material and the oxygen tank with an aluminum-lithium design being built in Russia. Other hydraulic and control system changes will also be made, some employing Russian components flown previously on the Buran shuttle. The DC-XA is scheduled for its first flight in April 1996.

NASA's role in President Clinton's 5 August 1994 policy was implemented on 9 March, when the agency selected three industry teams to negotiate initial 15 month, $8-million preliminary design study contracts leading to development of an X-33 suborbital flight-test vehicle to demonstrate the technologies needed for a new reusable launch vehicle (RLV). The three teams, Lockheed Advanced Development Company and Martin Marietta (now Lockheed Martin) teamed with Rocketdyne, McDonnell Douglas Aerospace teamed with Boeing, and Rockwell International Space Systems Division teamed with Northrop Grumman and Rocketdyne, will each pursue a different single-stage-to-orbit (SSTO) vehicle design. The Lockheed Martin team proposed a vertical launch, horizontal landing lifting body configuration; McDonnell Douglas offered a vertical launch, vertical landing vehicle similar to its current DC-X configuration; and the Rockwell team's design is a vertical launch, horizontal landing winged vehicle. The selection was made only two months after issuance by NASA of a Cooperative Agreement Notice, which requires the contractors to participate with NASA in funding and conducting the development.

In May, the United States Air Force also provided $75 million to help support research toward X-33 development. Specific elements of the Air Force effort, managed by Phillips Laboratory, include conducting the flight operations of the DC-X (see above), flight-testing a new Rocketdyne aerospike engine aboard the SR-71 Mach 3.3 aircraft to evaluate the aerospike's thrust-vectoring capability (see below), and ground-testing a Russian hydrogen-oxygen D-57 rocket engine with Aerojet in Russia next year.

Although the X-33 programme's goal is development of an SSTO vehicle, the technologies to be demonstrated would also be applicable to other fully reusable launch configurations; for example, two-stage-to-orbit. NASA's plans allocate about $650 million over the next five years to X-33 development, with an equal contribution to be made by industry. Development of the operational launcher that succeeds the X-33 is expected to be financed by industry, which could make the necessary investment (estimates range from $5 billion to $18 billion) only if the United States government were a major customer for launch services.

In a parallel announcement on 8 March, NASA selected the team of Orbital Sciences Corporation and Rockwell International Space Systems Division for negotiation on a smaller, partly reusable orbital launcher, the X-34, whose goal is to demonstrate low-cost, fast-turnaround launch operations for small commercial and scientific satellites. On 30 March the companies created a new joint venture, American Space Lines, to develop the new vehicle and to market and operate its services. The development programme is expected to cost $170 million. NASA's contribution is $70 million, for which it will receive two flights to be used for technology demonstrations and hypersonic research. The two industry team members will each contribute $50 million and will also assume the risk of any overruns. As currently planned, the X-34 will be launched from a Boeing 747 aircraft. Its first stage will be reusable, flying back to its base after launching the second (expendable) stage, which then will carry payloads up to 1,100 kg into LEO. Oxygen-kerosene engines being considered for the reusable first stage include Rocketdyne's MA-5 and RS-27 (which power the Atlas and the Delta respectively), and two Russian engines, a modified RD-120 (the Zenit's second-stage engine) and the NK-31. A new low-cost engine being developed by NASA's Marshall Space Flight Center will power the expendable upper stage. The first X-34 orbital flight is scheduled for 1998.

On 9 May, McDonnell Douglas announced its decision to develop the Delta-3 launcher, based on a commitment by Hughes to purchase a minimum of 10 launches through 2005, beginning in 1998. The Delta-3 will use nine Alliant Techsystems (formerly Hercules) graphite-epoxy solid-propellant boosters, each larger than the current

Delta-2's boosters, a larger payload fairing than the Delta-2, and a new cryogenic upper stage powered by a 106-kN thrust derivative of Pratt & Whitney's RL-10 engine, the RL-10B-2. Its payload capacity will be 3,800 kg to a geosynchronous transfer orbit, adequate for the Hughes HS-601 spacecraft.

On 5 January, Arianespace announced plans to contract with Ariane-5 manufacturers for 14 vehicles to be launched through 1999, serving as a production checkout and cost-reduction phase. The final contracts, signed on 8 June, also added five more vehicles to the previous (1988) 50-shipset order for Ariane-4 launchers to cover the five-year transition period from 1996 through 2000. A subsequent guaranteed-price contract is planned for at least 50 and possibly over 80 Ariane-5s to cover operations from 1999 through 2010 or 2015. However, on 9 June the French space agency (CNES) revealed that the agency had contracted with several Russian and Ukrainian companies to conduct research on building key elements of the Ariane-5. The contracts were with Khrunichev (Russia), for the Ariane-5 upper stage, and NPO Yushnoye (Ukraine), for a liquid-propellant alternative to Ariane-5's current solid-propellant boosters. CNES does not expect these research studies to lead to hardware development contracts, and early in June signed agreements with Germany, Italy, and Sweden totalling $22 million to begin work on a projected $2-billion Ariane-5 upgrade program, which was subsequently approved at a meeting of ESA's government ministers in October.

The first launch of the Ariane-5, originally scheduled for April, had been postponed to October, then to November, but delays resulting from abort of a main-stage full-duration test firing (see below) on 30 May due to improper software operation, a burst oil line, and both oxygen and hydrogen main-stage propellant leaks necessitated further rescheduling to January 1996 and then again to late April 1996. The maiden launch will carry the four Cluster science satellites described below. The vehicle's $7.4 billion development cost (which includes a new launch facility at Kourou, the first two flights, and a $220 million overrun due to the delays) was shared by France (46.2 per cent), Germany (22 per cent), Italy (15 per cent), Belgium (6 per cent), and the other eight ESA partners (11 per cent).

BPD Difesa e Spazio (Italy) announced on 1 June its intent to develop a new small launch vehicle without government funding. The three-stage Vega is designed to lift 250-700 kg payloads to LEO, using BPD's Zefiro solid propellant rockets for the first two stages and the company's solid propellant Iris motor for the third stage.

Japan completed this year a development plan for the H-2A, an advanced version of the H-2 launch vehicle. The upgrade, expected to cost about $650 million over the next five years, is aimed at halving the cost of a launch, currently about $200 million. Foreign components will be considered, including Russian rocket engines, as noted below, and possibly European rocket technology.

On 19 October, the Australian Space Office and the Cosmos Group, representing

Energomash (Russia), announced a joint venture to develop a new small launch vehicle (1,000 kg to LEO) and to provide commercial launch services from either Woomera or another location in northern Australia. The new vehicle, named Seagull, would be developed by the State Rocket Center in Maiss, Russia, using an engine to be either adapted or developed by Energomash. Some production would eventually be transferred to Australia.

III. UNMANNED EARTH ORBITAL ACTIVITIES

A. Telecommunications

1. Fixed-Base Communication Systems

During its 12-16 December meeting, Intelsat's Board of Governors, for the first time in the organization's history, approved the leasing of capacity from a non-Intelsat spacecraft. The international organization will pay India's Department of Space $100 million over 10 years, beginning in January 1998, for the use of 11 C-band transponders aboard Insat-2E, scheduled for launch late in 1997.

Intelsat 706, the first of three 3.8 tonne Intelsat-7A spacecraft built by Space Systems/Loral (United States), was launched by an Ariane 44LP on 17 May and began commercial service on 8 July from its 307 degree east longitude slot. Together with the Intelsat 705 that became operational on 8 May, the new spacecraft's 26 C-band and 14 Ku-band transponders will provide direct-broadcast coverage to small-aperture receivers in Latin America. Its design lifetime is 15 years.

Intelsat's first commercial competitor, PanAmSat Corporation (United States) completed its global network in September, following the successful launch of PanAmSat (PAS)-4 on 3 August aboard an Ariane-4. PAS-1 and PAS-2, launched in 1988 and 1994 respectively, serve the Atlantic and Pacific Ocean regions. The 3,050 kg PAS-4, built by Hughes on a standard HS-601 bus, has 16 C-band and 24 Ku-band transponders. It went into commercial service to 14 pre-launch customers in September. PAS-3 was lost as a result of the December 1994 Ariane failure (see above), and will be replaced in December 1995 by PAS-3R, which will then help PAS-1 meet the Atlantic region demand.

AT&T's Telstar 402R, the replacement for Telstar 402 (lost due to a pyrovalve setting off a fuel explosion about 10 minutes after launch in April 1994), was launched by an Ariane 42L on 24 September. The 3,400 kg spacecraft carries 24 Ku-band and 24 C-band transponders, and will serve United States customers for television, direct-broadcast, and data relay for 13 years from its position at 89 degrees west longitude. The launch was Ariane's 50th. A lawsuit by AT&T and a countersuit by Lockheed Martin, the manufacturer of Telstar 402, were settled out of court earlier this year

Fifteen United States companies filed applications with the United States Federal Communications Commission (FCC) for Ka-band licenses in time to meet the FCC's 29 September deadline. The applicants were AT&T, Echostar Communications, GE American Communications, Hughes Communications, KaStar Communications, Lockheed Martin, Loral Aerospace, Morningstar Satellite Corporation, Motorola, Netsat-28, Orion Network Systems, PanAmSat, Teledesic, TRW, and VisionStar. They plan either LEO or GEO systems, some new and some expansions of previously announced systems, pending global standards that were to be set by the World Radiocommunication Conference in November. The new concepts include AT&T's 12-satellite VoiceSpan, Lockheed Martin's 9-satellite Astrolink system, Loral's three-satellite CyberStar, and Motorola's 4-satellite Millennium network, all proposed for GEO slots.

New 175-channel United States direct-broadcast services, initiated in June 1994 by Hughes' DirecTV and United States Satellite Broadcasting (USSB), had signed up over 500,000 customers by the end of 1994. Projections anticipate 3 million customers by the end of 1996. As of 31 December 1994, orders for the $700 and $900 45-cm Digital Satellite System receivers exceeded the manufacturer's (Thomson Consumer Electronics) monthly production capacity of over 100,000 units. By June 1995, over one million had been sold. A third satellite, DBS-3, was launched aboard an Ariane 42P on 9 June to increase the total number of available channels to about 200 and to serve as backup for DBS-1 and DBS-2. The three spacecraft share a single GEO slot at 101 degrees west longitude.

Competition for the North American direct broadcast market began this year. A Canadian company, Tee-Comm Electronics, created AlphaStar in March by leasing more than half the 24 Ku-band transponders on AT&T's Telstar 402R satellite, launched on 24 September (see above). The new service to 61-cm home antennas, which will offer 110 television and 20 audio channels, was scheduled to begin in December, and will be expanded to over 200 channels in 1997 using Telstar-5. Customers in Alaska and Hawaii will also be served via slightly larger (76-cm) antennas. Echostar Communications Corporation also began service in September, using a Lockheed Martin satellite launched in August aboard a Chinese Long March rocket. A second Echostar satellite is scheduled for launch next year.

On 23 February, NASA awarded Hughes Space and Communications Company a $482 million contract for three Tracking and Data Relay Satellites (TDRSs), replacing the previous generation of TDRSs built by TRW. The new generation is based on the Hughes HS-601 bus, with a design lifetime of 11 years. In April, TRW, the former TDRS contractor, filed five formal complaints on the contract award, but they were rejected by the United States General Accounting Office on 10 July. The time required to complete the legal review, however, delayed the first launch of the new series from April 1999 to July 1999.

Hughes Communications and PanAmSat entered the 30 million customer Latin

American direct broadcast market in March. PanAmSat signed a contract with Hughes Space and Communications Company on 7 March for its third direct broadcast satellite, to be dedicated to the Latin-American market, and Hughes announced on 9 March that it had formed a new partnership, Galaxy Latin America, with companies from Brazil, Mexico, and Venezuela to deliver 144 television channels (72 in Portuguese; 72 in Spanish) and 60 music channels direct to households in the Caribbean, Mexico, Central America, and South America. Both broadcasters expect to start service in January 1996, PanAmSat with its PAS-3R satellite, scheduled for launch in December, and Hughes with its Galaxy-3R satellite, to be launched in late October. Construction of the first Galaxy Latin America ground uplink center was started in Long Beach, California on 20 April. Hughes plans to use a dedicated satellite, Galaxy-8I, for Galaxy Latin America service after it is launched in 1997 or 1998. Receivers for the Latin-American broadcasts will require antennas slightly larger than those currently used in the United States for DirecTV: 61 cm vs. DirecTV's 45 cm.

Hughes also initiated a 50-channel direct broadcast venture in Japan, DirecTV-Japan, in partnership with three Japanese companies, Culture Convenience Club Ltd (42.5 per cent), Space Communications Corp. (10 per cent), and Dai Nippon Printing Company (5 per cent). Hughes holds a 42.5 per cent interest in the new venture, which was announced in September.

In April, Hughes Network Systems initiated commercial operation of a high-speed satellite system, DirecPC, to transmit a wide range of services direct to office or home desktop computers. Services include delivery of software, video, news, and Internet data at about 50 times the speed available on commercial telephone lines. The small dish receiver is priced at $1,295; basic DirecPC service costs $16 per month. On 2 May Loral Corporation filed an application with the United States FCC for a new $442 million geostationary satellite system called CyberStar, to deliver high-speed, low-cost communication and data services to computers in the United States. The first CyberStar satellite would be placed at 110 degrees west longitude in 1998. It would use spot beams operating at Ka-band frequencies to transmit digital data via small, low-cost receiving antennas 100 times faster than by ground-based telephone systems. Similar applications had been filed with the FCC in 1994 by Hughes' Spaceway (United States) and Teledesic (United States). A number of other applications for Ka-band systems were filed in September (see above).

Hughes Space and Communications Company unveiled its latest satellite model, the HS-702, in October. With twice the capacity (up to 90 transponders) of the current standard HS-601 bus and three times the power (11 kW, with planned upgrading to 15 kW), the new spacecraft will weigh up to 4,600 kg. It is claimed to cost about the same as the higher-end HS-601 satellites, require the same two years for manufacture, and it can still be launched by currently available medium-to-heavy launchers. Mass savings accrue from the use of a high-specific-impulse xenon ion propulsion system, which uses only 5 kg/year of propellant and therefore saves hundreds of kilogrammes of spacecraft mass (see below), gallium arsenide solar cells, smaller antennas, and a modular design offering low cost, payload flexibility, and reduced manufacturing time. The first two HS-702 spacecraft have been ordered by Hughes Communications for Galaxy-10 and a ground spare, Galaxy-11.

On 31 October 1994, an Ariane 42P launched Astra-1D, Societe Europeenne des Satellites' (SES's) fourth direct-broadcast satellite. The 2,900 kg Hughes HS-601 spacecraft carries 24 transponders, all used for television broadcasting from the geostationary orbit at 19.2 degrees east longitude. Astra-1D joins three other Astra satellites collocated in the same slot. It incorporates software that implements an advanced station-keeping strategy conceived and developed by DLR's GSOC to control the four satellites' relative motions so as to avoid any collisions. SES is the only organization in the world having more than two satellites in the same GEO slot.

In July, Eutelsat selected Aerospatiale (France) to build three Eutelsat-3 spacecraft, with options for four more. Other competitors were Lockheed Martin (United States) and Matra Marconi Space (France). The 3 tonne Spacebus 3000 satellites will carry 24 transponders for direct-broadcast television and telecommunications services and will have a design lifetime of 12 years. Eutelsat also exercised an existing option with Matra Marconi Space for Hot Bird-3, a 20-transponder direct-broadcast satellite to be placed at 13 degrees east longitude. A third order was placed with NPO Prikladnoi Mekhaniki (Russia), which teamed with Alcatel Espace (France) to design and build an 18-transponder telecommunications satellite to be orbited at 48 degrees east longitude early in 1998. Eutelsat committed a total of $1.1 billion to the three projects.

Negotiations for construction and launch (in late 1999) of a $600-million French communications technology testbed satellite neared completion this year. Named Stentor, the project was first announced in June 1994. Technologies to be evaluated and demonstrated during the projected nine-year lifetime of the 1,800 kg satellite include electric propulsion, advanced solar arrays, new batteries, on board processing, and a deployable radiator. Funding is be provided by the French space agency (CNES), France Telecom, the French arms agency Délégation Générale pour l'Armement, and about 10 per cent from the three main industry participants, Aerospatiale, Alcatel Espace, and Matra Marconi Space.

Russia's Informkosmos announced on 16 December 1994 that it will build and launch two Gals-R direct-broadcast satellites for China's Roosevelt Commercial Satellite Company. The first launch of the 24-transponder spacecraft, which will serve the Asia-Pacific region, is scheduled for 1998.

On 20 September, GasCom (Russia) selected Space Systems/Loral (United States) to build the payloads and other electronic equipment for two Yamal communication satellites, to be built by RSC Energia for use by the gas company RAO Gazprom in its internal communications network. The satellites, each carrying 12 C-band transponders, are to be launched by a single Proton in 1997. They represent the first commercial procurement of Western satellite equipment by a Russian company.

On 30 April, Hungary's Magyarsat Ltd. expanded its prior agreement to lease transponders aboard Israel's 7-transponder Amos satellite, scheduled for launch by Ariane in January 1996. The new agreement establishes Hungary's first satellite, the 8-transponder, $140-million Hungarian Central European Regional Satellite (CERES), to be built by Israel Aircraft Industries and placed in the same GEO slot as Amos. Magyarsat will lease Amos transponders until CERES is launched in 1998. The Hungarian government provided the necessary financial base for CERES by agreeing to lease two of its transponders (4 channels) for an initial annual price of $10.8 million. CERES's customer base will include Hungary, Austria, the Czech Republic, Poland, Romania, and Slovakia. It is the first commercial satellite built by Israel for export.

A new generation of lightweight GEO commercial communication satellites began with an order placed in May for Indostar, a direct-to-home broadcast satellite to be built by CTA Inc. (United States) for Indonesia's Bimentara Citra. The 1,385 kg satellite will fly as a secondary payload aboard Ariane in late 1996 or early 1997.

Mexico began a six-month pilot programme in May to evaluate the Hughes Medical Tele-Imaging System, in which doctors in a hospital located in Tuxtla-Gutierrez, Chiapas, in southeast Mexico, will work via satellite with doctors in Mexico City's Centro Médico Nacional. Each hospital has patient monitoring equipment, an X-ray scanner, a videocassette recorder and monitor, a computer workstation, and a satellite dish, all supplied to Mexico's Institute of Social Security and Services for Government Employees by Hughes Electronics Corporation (United States).

Japan's first digital direct-to-home television broadcast service system was initiated with the Atlas launch on 28 August of Japan Satellite Corporation's JCSat-3. The satellite, built by Hughes Space and Communications Company (United States) and operated by Digital Multi-Channel Planning Company Ltd, has 12 C-band and 28 Ku-band transponders. It will provide voice, data, and fax services in Japan as well as about 50 channels of digital broadcast television. Although the spacecraft became operational in October, digital television service will be delayed until low-cost receivers are available on a production basis, expected to arrive early in 1996.

The next day an Ariane 44P orbited Japan's N-Star A, the first of a two-satellite system owned by the telephone company NTT and a subsidiary mobile communications company NTT DoCoMo. The 3.4-tonne spacecraft, a FS-1300 model built by Space Systems/Loral (United States), has 6 C-band, one S-band, 8 Ku-band, and 11 Ka-band transponders. It will provide telephone service, maritime communications, and high-speed data services to both fixed and mobile receivers during its 10-year lifetime.

Korea Telecom's Koreasat-1 was launched on 5 August by a Delta-2 rocket from

Cape Canaveral, Florida, but was short of its intended orbit by about 6,350 km due to the failure of one of the Delta's nine solid-propellant booster rockets to separate after completing its firing. The failure was later traced to a damaged detonator cord. The satellite's on board propulsion system was used to correct the orbit, but the expenditure of propellant that was needed to do so has reduced Koreasat-1's life to about 4.5 years instead of the planned 10 years. It was the first failure of a Delta launcher after 49 successes. Built by Lockheed Martin, Koreasat-1 carries 15 Ku-band transponders, 12 for fixed point-to-point communications and three for direct television broadcasting to homes equipped with 46 cm dish antennas. It entered commercial service in September.

China placed its first order for a 100 per cent Chinese-owned and operated commercial satellite system on 18 August. The China Orient Telecomm Satellite Company Ltd. issued a $100-million contract to Lockheed Martin (United States) for ChinaStar-1, plus an option for ChinaStar-2. The 3,200 kg A2100 ChinaStar-1 spacecraft will be launched in the fourth quarter of 1997 by a Long March LM-3B rocket. It has a design lifetime of 15 years and will carry 18 C-band and 20 Ku-band transponders. The contract includes ground equipment and training of Chinese engineers. China's Ministry of Post and Telecommunications also bought an HS-376 communications satellite from Hughes Space and Communications Company (United States) in October. It will be launched on a Long March rocket in July 1996.

On 15 October, the Egyptian Radio and Television Union ordered a direct-broadcast television satellite from Matra Marconi Space. The $158 million contract includes construction of the 1,700 kg, 12 Ku-band transponder satellite (whose communication payload will be built by Alcatel Espace), a 1997 Ariane launch, and satellite control centres in Cairo and Alexandria

2. Mobile Communication Systems

The United Nations Department of Peacekeeping Operations (DPKO) began on 1 March to establish a mobile communications system for DPKO field commanders that enables them to use existing commercial satellites for key information, decision-making, and command functions. The $20 million system will employ six vans, equipped with sophisticated satellite ground stations, that can be transported to field troop locations via airlift.

Fifty-six of Inmarsat's members unanimously endorsed creation of the Inmarsat-P system at a meeting held on 9 December 1994. The company's target of $1 billion in investments by Inmarsat's members (toward an estimated first-generation cost of $2.6 billion for the new system) was exceeded by 16 January, when $1.4 billion was committed to the new company. Response was so favourable that Inmarsat had to set a limit of $94 million for any single signatory in order to ensure broad participation. The first Board of Directors of Inmarsat P met on 24 January. The company was subsequently split off from Inmarsat as a separate entity in April, with former Inmarsat Director

General Olof Lundberg as its Chairman and Chief Executive Officer, and was subsequently renamed ICO Global Communications. A $1.3-billion contract for construction of the new company's 12 satellites, each weighing 2.1 tonnes, was signed with Hughes Space and Communications International (United States) on 20 July. Hughes also invested $94 million in ICO.

The Skyways Alliance was created in March by eight communications organizations to utilize Inmarsat's satellites in conjunction with their countries' ground stations to deliver satellite voice and data services to aircraft crews and passengers. The eight signatories, representing Indonesia, Italy, Japan, Malaysia, the Philippines, South Korea, Thailand, and the United States, were later joined by the International Telecom Authority of Taiwan.

The United States FCC on 31 January granted licenses to three mobile satellite communications companies, Iridium (Motorola), Globalstar (Loral), and Odyssey (TRW), but deferred action for a year on applications by Constellation Communications and Mobile Communications Holdings because they did not meet the FCC's financial requirements. Globalstar completed its initial financing phase on 14 February with $494 million in equity financing toward a total system cost of $1.95 billion. The balance will be raised through debentures, additional equity offerings, vendor financing, and franchise fees.

Orbital Communications Corporation (Orbcomm) launched the first two of its small (40 kg) messaging satellites aboard a Pegasus rocket on 3 April as precursors of the company's planned 36 satellite constellation. Problems were experienced first with Orbcomm 2, whose uplink receiver malfunctioned five orbits after launch, and then with Orbcomm 1, which was found on 15 April to have a problem with its customer communications sub-system. Communications were re-established with Orbcomm-2 on 13 May, and Orbcomm-1 was fully restored on 13 June. Both spacecraft began functional operation testing in July, conducted "beta-test" (prototype) demonstrations beginning 1 November, and are expected to go into commercial service in the United States on 1 February 1996, in Canada and Mexico later in 1996, and in Europe and Latin America in 1997. An agreement with Nuova Telespazio (Italy), signed in February, was the 22nd international license for Orbcomm services in 69 countries. The $220 million system is designed for global paging and two-way messaging using hand-held devices, as well as fleet management, cargo tracking, and monitoring of remote assets. Originally estimated to cost $150 million, the system has been upgraded from 26 to 36 satellites with five year lifetimes instead of the original four years.

On 9 August, a competitive United States system, Starsys Global Positioning, Inc., obtained the financing it needed to apply for an FCC license to build and operate its 24 satellite LEO communications network. GE Americom purchased 80 per cent of Starsys stock, agreeing to invest about $46 million in the first two Starsys satellites and the first year of operation. The complete system is expected to cost $150-$190 million. The first launch is estimated to occur in late 1997, assuming the company receives its FCC license in late 1995 as planned. Orbcomm had obtained its license in October 1994.

The third United States "Little LEO" competitor, Volunteers in Technical Assistance (VITA), received its FCC license in July, but suffered a major setback when its first satellite was lost as a result of the failure of the first Astria launch on 15 August (see above).

MSAT, the first GEO satellite dedicated to mobile communications using hand-held terminals, was launched successfully by an Atlas-2A on 7 April. MSAT's payload, built by Spar Aerospace (Canada) has 16 L-band transponders and uses spot beams to cover the United States mainland, Hawaii, Alaska, the Caribbean, and the waters of the continental shelf out to about 200 miles. Service was initially expected to begin in June, but was delayed until December because of problems with two of MSAT's solid-state power amplifiers, which shut down unexpectedly on 31 July and 13 October. The satellite is interconnected with ground-based United States cellular telephone systems that currently cover areas having 190 million subscribers. MSAT, also called AMSC-1, generates 3 kW of power and is the first spacecraft to use springback graphite antennas, which are 6.7-m x 5-m ellipses weighing only 20 kg. American Mobile Satellite Corporation has invested $454 million in the system since 1988.

On 21 January, Alcatel Espace (France) and Alenia Spazio (Italy) signed a $500 million contract with WorldSpace Inc. (United States) to deliver a global satellite radio system. The three 2,200 kg GEO satellites, which will use the basic Italsat bus, are to be launched and ready for digital audio broadcasting of news, entertainment, and educational programmes by 1997. CaribStar (at 75 degrees west longitude) will cover the Caribbean and Central and South America; AfriStar (at 12 degrees east) will broadcast to the Middle East and Africa; and AsiaStar (at 105 degrees east) will transmit to Asia. The StarMan receivers will use antennas smaller than 10 cm in diameter.

On 4 November 1994, the German messaging satellite Safir-R, owned by OHB Systems of Bremen, was launched from the Baikonur Cosmodrome aboard a Zenit rocket as part of a Russian Resurs payload. A second satellite is scheduled for a Zenit launch in 1996.

On 19 January, Afro-Asian Satellite Communications (India) signed a $700 million contract with Hughes Space and Communications Co. (United States) for a two-satellite hand-held telephone network in southern, central, and eastern Asia and Africa. The HS-601 satellites are scheduled for launch in December 1997 and March 1998. The network, called Agrani, will employ a ground system consisting of two major control stations and four "gateway" relay stations to communicate between hand-held telephones (estimated to cost $700-$1,000) at a price to users of about $2 per minute for international calls.

Apstar-2, owned by APT Satellite Company of Hong Kong, was lost during launch by a Chinese Long March 2E rocket on 26 January. It was covered by a $160-million insurance policy written by an underwriting team led by Johnson and Higgins (United States). The cause of the failure was later announced (in August) as the breakup of either the fairing that protects the payload or the satellite-rocket interface structure due to excessive aerodynamic forces during the launch. APT contracted with Space Systems/Loral on 1 June for a replacement, Apstar-2R, to be launched in late 1996 or in early 1997 on a Long March 3B.

3. Navigation and Position Location

In mid-May, ESA and the Commission of the European Union (EU) approved a four year, $200 million programme to build ground stations and lease capacity of navigation payloads aboard four Inmarsat-3 satellites scheduled for launch in 1995 and 1996. The system will permit about 6,000 airport runways in Europe to use the 24 satellite United States Global Positioning System (GPS) for airport vicinity operations, including Category-1 landings.

Following a round-trip validation flight on 25-26 July from the United States to Europe, the United States Federal Aviation Administration issued to Sun Country Airlines (United States) its first approval for worldwide operational GPS use for primary navigation, without Omega or inertial navigation system backup. The airline uses Boeing 727-200 aircraft and a Trimble TNL8100 GPS system. Beginning in October 1994, Airbus Industrie (Europe) conducted over 110 automatic landings of A340 aircraft with differential GPS equipment, demonstrating compliance with Category-1 and Category-2 landing requirements

A new application for GPS was tested in 1995 using the Radcal and Spartan/Gadacs spacecraft: attitude determination for relatively small spacecraft (e.g., 1 m). Accuracies of 0.5 degree were obtained using on board miniaturized electronics in conjunction with ground processing. Future plans call for improving the on board equipment to permit fully autonomous attitude determination.

A report released on 31 May by independent expert panels of the National Research Council and the National Academy of Public Administration (both of the United States), "The Global Positioning System: Charting the Future," recommended that the United States DOD terminate use of selective availability on GPS satellites. This feature prevents civil users of the system from obtaining the high level of precision available to DOD. The basis for the recommendation was that current differential GPS systems now in widespread use make the selective availability feature less effective, and therefore the DoD should replace that feature with active jamming or other denial techniques to prevent a potential adversary from using the DOD's own system to attack the United States. The report's recommendation was not accepted by the DOD. Meanwhile Russia has scheduled its launch of the final three Glonass navigation satellites for October, completing the 24 spacecraft constellation plus one on-orbit spare.

At the International Astronautical Congress, held 2-7 October in Oslo, Norway, Japanese researchers announced a $2 million project to monitor the movements of blue whales in the Antarctic Ocean using GPS sensors. The system will use a dedicated 50 kg Whale Ecology Observation Satellite to be launched into polar orbit in 1997 as a secondary payload aboard an H-2 or Long March rocket. Approximately 100 blue whales will be tagged with a sensor-laden harpoon attached to a 10 kg electronic float carrying a recording system, data processor, GPS receiver, and UHF satellite transmitter, all powered by a 5W power source similar to that used in self-winding wristwatches and driven by the whale's swimming motion. The floats are expected to last for two to three years.

B. Remote Sensing

1. Earth Observations

A report summarizing the first 10 years of activities by the international Committee on Earth Observing Satellites (CEOS) was released in August by Smith System Engineering Ltd (United Kingdom). "Coordination for the Next Decade," assembled by ESA, calls for creation of an international Earth observation database that would include every measurement made by current and planned satellites (12 new Earth observing spacecraft are scheduled to be launched by 1997). It would be available worldwide on the Internet, and if financing can be obtained (about $300,000 is estimated to be needed), the initial database could be available in about two years.

Ball Aerospace and Worldview Imaging Corporation (United States) announced on 25 January, the formation of a new joint venture, Earthwatch, Inc. The new company plans to launch its first satellite, named EarlyBird, in 1996 (see above). Its panchromatic sensor will have 3 m resolution; a multispectral sensor will also provide 15 m resolution. The second satellite, planned for a mid-1997 launch, will have 1 m panchromatic resolution and a multispectral sensor with 4 m resolution. It will be called QuickBird.

A new high-resolution satellite project, Orbview, was announced on 2 May by Orbimage (United States), Orbital Sciences Corporation's new remote sensing subsidiary. Orbview replaces the previous Eyeglass project, which expired with the withdrawal of Orbimage's former partners, Litton Itek Optical Systems (United States) and GDE Systems (United States). In June, the Eirad Company (Saudi Arabia) bought a 20 per cent share in the new company in exchange for exclusive Middle East distribution rights for Orbview and SeaStar images. The 146 kg Orbview satellite, which Orbimage said will be much less costly than Eyeglass, will provide panchromatic (black and white) imagery with 1 m resolution, panchromatic data with 2 m resolution, and multispectral resolution of 8 m. It will be launched into a 460 km circular polar orbit by a Pegasus XL rocket in 1997, where its expected operational life will be three years. Total system cost, including a follow-on satellite, is estimated to be $250 million.

GDE Systems (United States), one of the former partners in the now defunct Eyeglass consortium, filed for and on 14 July received a license from the United States Department of Commerce (DOC) for a new 1 m resolution commercial Earth observing satellite. A total of four United States licenses for high-resolution systems have been granted; Orbview's and the new GDE Systems' ventures now join previously issued licenses for Lockheed Martin's Space Imaging Inc. and Earthwatch, Inc. (see above). Another new United States license was issued by DOC on 1 August to Motorola for an experimental single satellite system.

On 8 November 1994, NASA's Ames Research Center announced the establishment of the Center for Health Applications of Aerospace Related Technologies (CHAART). CHAART's initial activities, which apply satellite imagery and geographic information systems to both on-going and new disease studies, are co-sponsored by the United States National Institutes of Health. Health ministers from developing nations attended a workshop held in April at the University of Maryland to explore applications of CHAART's efforts in their countries. CHAART builds on programmes begun by Ames Research Center in 1985 with studies of malaria.

In December 1994, NASA issued a $2.9 million grant to Ohio State University and the Vexcel Corporation (both of the United States) to map the entire continent of Antarctica to a resolution of 25 m using Canada's Radarsat-1, which was to be launched by a United States Delta-2 in the fourth quarter of 1995. The mapping is to be conducted during an 18 day period in September 1996, during which the spacecraft will be oriented 180 degrees from its normal attitude to point its C-band synthetic aperture radar sensor south instead of north.

The World Monuments Fund (United States) announced in February that observations by the Space Radar Laboratory mission on the Shuttle Endeavour in October 1994 had discovered previously unknown extensive infrastructure (e.g., a hydrological system of canals and reservoirs) surrounding the ancient 4,800 sq. km city of Angkor in Cambodia.

Four United States federal agencies signed a memorandum of understanding on 10 March to formalize the Multi-Resource Land Characterization (MRLC) consortium, which provides a central, coordinated mechanism to purchase and process satellite images. The four agencies are the National Biological Service, the Environmental Protection Agency, the United States Geological Survey, and the National Oceanic and Atmospheric Administration.

ESA's second Environmental Research Satellite, ERS-2, was launched into its 780 km polar orbit by an Ariane rocket on 20 April and began operations in July. Its orbit is designed so that it follows its predecessor, ERS-1, by about 50 minutes, giving investigators a new tool to measure topography parameters of the Earth by successive passes of the satellites' synthetic aperture radar instruments. The 2,500 kg spacecraft carries seven main instruments, including a Global Ozone Monitoring Experiment which was not in the payload of ERS-1. The total cost of the two spacecraft constellation, including operations, was about $2 billion.

Cray Systems (United Kingdom) announced on 2 March the creation of a new commercial remote sensing data centre at the University of Dundee. The Dundee Centre for Coastal Zone Research, as its name implies, will focus mainly on environmental assessments of Europe's 140,000 km of coastal zones, using data from Europe's ERS-1 and ERS-2, France's SPOT, Canada's Radarsat, and the United States' Landsat satellites. Initial customers for the Centre's products are the British National Space Centre and the EU.

The United Nations' Food and Agriculture Organization (FAO) initiated in July a programme called Africover, which uses images from a number of remote sensing satellites to generate a set of digital vegetation and land cover maps for the entire African continent. The maps will be used by resource managers in the various African regions for monitoring land use and environmental changes, for early warnings of drought, crop failures, and insect infestations, and for watershed management. The entire Africover project could take 10 years and cost up to $60 million. The first element of Africover began in Kenya, funded by $5.4 million from Italy.

India's remote-sensing satellite IRS-1C, to be launched by a Russian Molniya in December, is equipped with a panchromatic camera having 8 m resolution, a multispectral sensor with 22 m resolution, and a wide-field sensor. These sensors aboard IRS-1C and its twin, IRS-1D (scheduled for launch in 1997) represent significant improvements over the most recent Indian spacecraft, IRS-P2 (launched by the first successful PSLV in October 1994), which has 36 m multispectral resolution. On 17 March India retired its first remote sensing satellite, IRS-1A, after seven years of service (its design life was three years). The first of a new IRS-P series of remote sensing satellites, to be launched by Polar Satellite Launch Vehicles (PSLV; see above), is scheduled for January 1996. IRS-P3 will carry a multichannel narrow-band modular optical scanner developed by DLR (Germany) for ocean research applications, as well as a wide-field sensor to monitor global vegetation in two visible-light and one infrared band.

Israel's Ofeq-3 satellite, launched on 5 April (see above), was said by manufacturer Israel Aircraft Industries to be suitable for a wide range of commercial and scientific missions. It will provide images with a resolution of better than 2 m to commercial customers through a joint marketing venture set up by Israel Aircraft Industries Ltd. (Israel) and Core Software Technology Inc. (United States). The Israeli and German space agencies signed an agreement in July to cooperate on a small Earth observation satellite for agricultural use, environmental monitoring, forestry, and land use management. OHB-System (Germany) will build the spacecraft for the $10 million

Project David based on the Safir satellite bus (see above), and El-Op Electro-optics Industries Ltd. (Israel) will build the 5 m resolution sensor, based on the instrument lost aboard Techsat Gurwin-1.

Chile's first satellite was launched from the Plesetsk Cosmodrome on 30 August as a secondary payload (to the Sich-1 Earth-observation satellite) by Ukraine's Tsyklon. The 50 kg FASat-Alfa, built by Surrey Satellite Technology Ltd. (United Kingdom), provides the Chilean Air Force with 100 m resolution. It also carries a 1 km resolution wide-angle camera, an ozone-measuring instrument, and a store-and-forward communication system.

2. Atmosphere and Ocean Observations

NASA launched NOAA-14 into a polar orbit for the National Oceanic and Atmospheric Administration (NOAA) aboard a Martin Marietta (now Lockheed Martin) Atlas-E booster from Vandenburg Air Force Base on 30 December 1994. The satellite was turned over to NOAA on 3 January to replace NOAA-11, launched in September 1988. The last two polar orbiting NOAA spacecraft, NOAA-N and NOAA-N-Prime, were ordered by NASA from Martin Marietta Astrospace (now Lockheed Martin) on 21 December 1994. Subsequent polar orbit weather satellites will be launched as part of a converged United States system that will integrate civil and defence weather data requirements and operations.

The second Geostationary Operational Environmental Satellite (GOES) in the GOES-Next series of five spacecraft was launched by an Atlas-1 vehicle from Cape Canaveral on 23 May; the first had been orbited in April 1994. The GOES-Next series differs from the previous generation of GOES satellites in that they are three-axis-stabilized, allowing them to operate 100 per cent of the time; they are equipped with an imager to monitor cloud cover and Earth surface phenomena; and they also carry a sounder to measure temperature and humidity at different levels in the atmosphere. GOES-9 was placed in a geostationary slot at 90 degrees west longitude for four or five months of testing, after which it will be moved to its final operational location at 135 degrees west.

NASA shipped a scatterometer and a Total Ozone Mapping Spectrometer (TOMS) to Japan on 1 November 1994 for the Advanced Earth Observing Satellite (ADEOS). The 3,200 tonne satellite, the heaviest ever developed by Japan, will also carry a French sensor and five Japanese instruments. It is scheduled for launch by an H-2 rocket in February 1996.

On 25 January Earth Satellite Corporation (United States) initiated a five month study aimed at detecting undersea oil reservoirs by searching the ocean's surface for oil slicks, building on the company's prior success in finding offshore oil slicks off Texas' Gulf of Mexico coast and California's Pacific coastline. The technique employs Europe's

ERS-1 radar sensors to detect flattening of the waves caused by oil, and Landsat's optical and infrared sensors to verify that the surface reflectance of the flattened area is indeed typical of an oil slick.

The Pegasus rocket that launched Orbcomm's first two satellites on 3 April (see above) also launched Microlab-1, a small LEO spacecraft carrying a lightning mapping instrument for NASA and a National Science Foundation instrument to test a method for early detection of greenhouse gas build up by using changes in the signals from GPS satellites to measuring temperature and humidity in the atmosphere. Microlab's Optical Transient Detector observed over 200 intra-cloud lightning flashes during a storm over Oklahoma in April, vs. only nine seen from the ground. The storm later generated a tornado, suggesting to meteorologists that multiple intra-cloud lightning events might be linked to tornado production.

The joint United States-French Topex-Poseidon spacecraft, launched in August 1992, began a three year extension of service after completing its originally planned three year mission on 12 August. The spacecraft creates global sea-level maps every 10 days in carrying out its function of studying ocean currents and their effects on long-term weather patterns. Its annual operating cost has been reduced from $30 million to $20 million, and its accuracy has been improved from the original goal of 13.3 cm to 4 cm.

On 24 October, the United States NOAA released a detailed map of the world's ocean floor, based on previously classified radar data collected by two United States Navy spacecraft, Seasat (launched in 1978) and Geosat (launched in March 1985), which were then integrated with radar data from Europe's ERS-1 to generate the map. The spacecraft measured swells and depressions in the ocean surface caused by gravity perturbations to an accuracy of about 2 cm, enabling determinations of the undersea features that produced the perturbations. The sea-floor map provides new data on the number of ocean-floor volcanoes (twice that of previous estimates), on plate tectonics, and on the creation of ridges by welling lava flows.

In yet another restructuring, NASA cut $12 billion from the 30 year programme cost of the Earth Observing System in July, bringing its total cost through 2023 to $33 billion. The savings are to be realized through the use of smaller satellites for the second and third series of planned satellites and by using new technologies in those spacecraft, possibly the technologies to be developed by the New Millennium program (see below). The first series of three satellites is already designed and the first, AM-1, is being built by Lockheed Martin for a scheduled launch in June 1998. The second, PM-1, is to fly in 2000, and the third, Chemistry-1, is scheduled for launch in 2002. On 20 September NASA issued a $398-million contract to TRW to build the spacecraft buses for PM-1 and Chem-1, with options for two more. The 3,200 kg spacecraft are over 6 m long, and will be inserted by Delta launchers into near-polar 706 km orbits. The system's mission is to measure, monitor, and document changes in the global environment, with particular emphasis on the effects resulting from human activities.

On 31 October 1994 a Proton rocket launched a 2,500 kg Russian meteorological satellite named Elektro into a GEO position at 76 degrees east longitude. Elektro completes the five satellite GEO constellation needed by the World Weather Watch programme for global coverage. The other four spacecraft are Europe's Meteosat (zero degrees longitude), two United States GOES spacecraft at 75 degrees west and 135 degrees west, and Japan's Geostationary Meteorological Satellite at 140 degrees east.

Chile's first satellite, FASat-Alpha, was launched by a Ukrainian Tsyklon vehicle from Plesetsk on 31 August (see above) to monitor ozone in the upper atmosphere and to conduct experiments in store-and-forward communications technology. However, once in orbit, the 50 kg satellite failed to separate from the main two tonne Ukrainian Sich-1 ocean observation payload, and was therefore unable to operate satisfactorily. FASat-Alpha was built by Surrey Satellite Technology Ltd. (United Kingdom) for $4.9 million, which included separation from Sich-1. Neither of the two pyrotechnic separation charges fired, but it is not known whether the failure was in the devices or in the communications link that was to have transmitted the firing signal. Chile plans to replace the spacecraft with FASat-Bravo within nine months.

C. Commercial Developments

On 9 January, Intelsat concluded the largest space insurance contract ever written, covering 10 launches during 1995-1997. The policy, whose premium is about $185 million, insures over $2 billion worth of launch-related costs associated with the orbiting of four Intelsat-7 and six Intelsat-8 spacecraft aboard seven Ariane-4 rockets and three Chinese Long March 3B vehicles. The insurance contract consortium, under the umbrella of International Space Brokers (United States), includes Crawley Warren & Co. Ltd. (United Kingdom) and Le Blanc de Nicolay (France). Intelsats 704 and 705, launched by Martin Marietta Atlas 2AS rockets in January and March, had been covered by previous insurance agreements.

On 15 March, the largest aerospace company in the world, Lockheed Martin, was created when the merger of Lockheed and Martin Marietta was approved overwhelmingly by both companies' shareholders. The new company has annual revenues of $23.5 billion. The company on 15 June announced the merger of its Atlas and Proton launch services, the latter formerly marketed through LKE International, into a new joint venture with Khrunichev (Russia) called International Launch Services (ILS). ILS is now exploring potential alternate Proton launch sites in Florida (United States), Brazil, and Australia.

On 28 November 1994 Orbital Sciences Corporation (United States) announced its purchase of Magellan Corporation for about $50 million. Magellan is a leading manufacturer of hand-held satellite navigation equipment. The purchase gives OSC the full range of capabilities needed for its Orbcomm system to link up with the GPS, supplementing previous agreements reached with Trimble Navigation Ltd (United States), Panasonic (Japan), Elisra Electronic Systems (Israel), and Torrey Science and Technology

(United States). Magellan's GPS receivers are currently priced at about $300; their most recent model, announced in August, will sell for about $200. In 1994 the company sold over 100,000 receivers to customers in more than 70 countries.

On 3 March, the shareholders of Alliant Techsystems (United States) approved the acquisition of Hercules Aerospace (United States), a manufacturer of large solid propellant rocket boosters. The $296 million acquisition was completed on 15 March. On 3 April, Raytheon (United States) announced the purchase of E-Systems (United States) for $2.3 billion. The acquisition gave Raytheon access to E-Systems' share in Lockheed Martin's high-resolution remote sensing venture Space Imaging, Inc., which will be of considerable value to Raytheon in carrying out its $1 billion contract to build an environmental monitoring system for Brazil.

In January, United States Air Force Secretary Sheila Widnall announced approval of a lease with Spaceport Systems International (SSI) to develop a commercial spaceport, the Western Commercial Space Center, for launches from Vandenburg Air Force Base in California. Payload processing and launch control will be conducted from Space Launch Complex (SLC) 6, originally built for Shuttle launches but never used. SSI received about $10 million from the United States during the past three years, plus a commitment (on 28 November 1994) from partner ITT for $30 million and about $1 million from the state of California. The company will focus primarily on small vehicle launch operations such as Taurus and Astria. On 16 March, the Western Commercial Space Center and the Air Force signed a 25 year lease for about 37 hectares of undeveloped land adjoining SLC-6.

A second United States commercial spaceport was authorized by the state legislature of Alaska in May, with $25 million in state funds approved for its development. The Alaska Aerospace Development Corporation plans to begin building the Kodiak Launch Complex on Kodiak Island in the Gulf of Alaska in 1996, with the expectation of providing full service polar orbit launch facilities for small vehicles such as OSC's Taurus, EER's Conestoga, and the Lockheed Martin's Astria as early as the fourth quarter of 1997.

Following a proposal by Eurospace (see "Highlights in Space 1993"), ESA in February announced a Small Missions Opportunity Initiative, requesting European industry to conduct two studies, each costing $488,000 and lasting nine months, aimed at creating a commercial consortium to build and launch small satellites. ESA plans to support the initiative by guaranteeing the consortium a minimum of 10 launch contracts for payloads (200 to 600 kg) during the first five years. Unlike all past ESA programs, the consortium would be allowed to use foreign vehicles to launch the satellites. The two study awards went to BPD Difesa e Spazio (Italy), which plans to develop a new small satellite launch vehicle (see above), and to Matra Marconi Space (France).

A Euroconsult survey of European commercial space ventures issued in February, reported 1993 revenues of $207 million for remote sensing images and ground facilities (21 per cent of which were for military purposes), $403 million for television broadcasting by Eutelsat and Société Européenne des Satellites (SES), and $53 million for mobile communications and position location (by Euteltracs and Inmarsat's Argos system). Smith System Engineering Ltd. (United Kingdom) reported space sales in the United Kingdom for the 12 months ending in June 1994 had grown from the previous year's total of $848 million to $1.1 billion.

A report issued by the European space industry organization Eurospace on 13 June, "Space - A Challenge for Europe," recommended that ESA focus on commercial space technologies such as satellite navigation, communications, remote sensing systems, and low-cost launch services (as well as military systems) rather than its present menu of high technology satellites, science, and human space flight. The report's rationale is that United States companies dominate the commercial satellite market, citing the facts that all seven of Europe's commercial television broadcast satellites were supplied by United States firms, that United States companies hold 66 per cent of the global market in commercial satellites, and that the combined annual sales of commercial products by the five largest United States space companies are more than triple those of the five largest European space companies.

In the first merger of second tier space companies across national boundaries, on 1 March Saab Ericsson Space (Sweden) purchased major shares of two small Austrian companies, Schrack Aerospace (an 80 per cent interest) and the Austrian Aerospace Company (a 49 per cent share). The action reflects recognition of the need for European space companies to seek business sources other than government contracts. The Swedish Space Corporation announced on 6 April its purchase of 50 per cent of the Norwegian Tromso Satellite Station for $800,000. This action merges the Earth observation data activities of Tromso and Sweden's Kiruna ground station in processing and marketing both radar and optical data from Europe's ERS-1 and ERS-2, Japan's JERS-1, France's SPOT, the United States' Landsat, Russia's Resurs, and Canada's Radarsat. Both SSC and Tromso also announced major expansion of their facilities for receiving and processing satellite imagery.

Under an agreement signed on 2 February by Eosat (United States) and Antrix, representing India's Department of Space, most of Eosat's revenue during the coming decade will be derived from images generated by ten Indian satellites. The company is currently marketing data from IRS-1B and IRS-P2, and will begin selling images from IRS-1C and IRS-P3 this year and from IRS-1D next year, after its January 1996 launch. Resolution of IRS-1C and IRS-1D is about 10 m.

A report issued by Euroconsult in May, "Asia-Pacific Satellite Communications and Broadcasting Market Opportunities and Prospects to 2005," forecasts a surplus of transponder capacity in the Pacific region of Asia from 1997 to about 2000, following the current shortage. Growth in the satellite television market is projected from 9 million homes in 1994 to 22 million in 2004, and the number of Asia-Pacific transponders in orbit is expected to double by 2000. Twelve new satellites for the region are to be delivered in orbit this year, with 17 more projected for 1996. The capacity surplus predicted for 1997 will be absorbed by new customer demand within three years, according to Euroconsult.

IV. MANNED EARTH ORBITAL ACTIVITIES

A. Space Station Development

NASA and Boeing on 13 January signed a $5.63 billion contract (through 2002) for developing the United States portion of International Space Station Alpha (ISSA). On 15 August, Khrunichev Space Center signed a $190 million contract with Boeing to deliver the 18 tonne Functional Energy Block (FGB) scheduled for the first space station launch in November 1997 aboard a Proton vehicle. Khrunichev expects to be able to meet the tight development schedule because 22 of the FGB's major subsystems and structures are directly derived from the Mir's Kristall module, and the other eight are derived from the Kvant-2 module currently attached to Mir. The FGB is 12.8 m long and 4 m in diameter, with a solar array span of 25 m. It has four docking ports and carries 16 propellant tanks (capacity 5.8 tonnes), with 38 thrusters for maneuvering and attitude control. It will provide the space station with power, attitude control, and computer capability during the station's construction period.

The new plan for ISSA involves a total of 73 launches for deployment, utilization, and servicing during the 55 months from November 1997 through June 2002: 28 by the United States Shuttle, 44 by Russian launchers, and one by Europe's Ariane-5. Assembly of the station is now expected to require up to 888 hours of extra-vehicular activity (EVA) by astronauts and cosmonauts, and subsequent maintenance will require 171 hours of EVA per year. ISSA's total planned mass in orbit by 2002 is 400 tonnes, it will have over 900 cubic metres of pressurized volume, and it will provide its crew of six with 110 kWe of power.

On 6 June, NASA announced plans to explore the prospects for building a new crew return vehicle to replace the Russian Soyuz after 2002. The first step, toward which NASA has committed $1 million, is the preliminary design of an experimental flight vehicle to test and demonstrate the necessary technologies. Tentatively called the X-35, pending review and approval by NASA for Fiscal Year 1997, the experimental vehicle would be 7.3 m long and would use a lifting-body aerodynamic configuration plus a steerable parachute for final descent. On 20 July, France proposed to the ESA Council that ESA design and build a crew return vehicle as the main European contribution to the space station, but the French proposal was later withdrawn because funding limitations would not permit the construction of both that vehicle and the pressurized laboratory already committed by ESA.

After years of deliberation, ESA's government ministers finally approved the agency's participation in ISSA at their 18-20 October meeting. The 17-year total commitment (1996-2013) is estimated to cost about $6.8 billion, of which Germany's minister agreed to provide 41 per cent, France committed 27.6 per cent, and Italy 17 per cent. Germany also agreed to pay 19 per cent of the estimated $2 billion Ariane-5 upgrade cost (see above). The ministers also ordered a 12 per cent cut in ESA's staff by 1998, along with restructuring of the agency's contract management procedures, and froze spending on ESA science missions for three years.

B. Earth-Orbital Flight Operations

NASA initiated action toward a major change in Shuttle operations in 1995. An exhaustive study was conducted by an independent team of former Shuttle programme managers and others, led by former Johnson Space Center director Christopher Kraft. Their report, published on 15 March ("Report of the Space Shuttle Management Review Team"), recommended that NASA consolidate all its Shuttle operations, which were being conducted by over 56 NASA contractors holding 85 separate contracts, under a single prime contractor. The team's report made it clear that such a move would not only reduce Shuttle operations costs but would also improve safety, efficiency, and capabilities of the Shuttle system. NASA briefed about 40 potential industry contractors on 21 August, and in September four companies indicated their intent to offer bids as prime contractor. They included the United States Space Alliance (USSA), a joint venture between Lockheed Martin and Rockwell International, which when combined perform about 66 per cent of current Shuttle operations, as well as Boeing, McDonnell Douglas, and Bamsi. A draft Request for Proposals is expected to be issued late this year, and a contract to take over Shuttle operations could be issued by the end of 1996.

Space Shuttle Atlantis returned to flight status on 3 November after two years of maintenance and refitting for Mir docking operations, carrying the Atmospheric Laboratory for Applications and Science (ATLAS). Instruments on this third ATLAS flight included the Belgian Solcon and the French Solspec. The main objectives of the 11 day mission were to study the Antarctic ozone hole and to measure solar radiation parameters, including the total energy transmitted to the Earth. The astronauts also deployed and recovered the German free-flyer Shuttle Pallet Satellite (SPAS), which carried an instrument package called the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere. The eight day SPAS mission measured trace gases that produce ozone and studied the dynamics of the atmosphere. The Atmospheric Trace Molecule Spectrometer (ATMOS) detected an absence of water vapour in the ozone hole, a finding which requires revision of current theories about the formation and maintenance of the hole. The SPAS rendezvous maneuver, in which the Shuttle approached the free-flyer from below rather than from above as has been customarily done in the past, was used by the Shuttle astronauts to practice for the subsequent Mir docking mission (see below).

The first Shuttle-Mir mission, a practice run for subsequent dockings, began with the launch of Space Shuttle Discovery on 3 February. The mission's primary goal was to test the rendezvous scheme, in which the Shuttle approached Mir to within 11 metres from below to take full advantage of gravity-gradient stabilization. Aborting the close approach was considered because of a leaking reaction control thruster aboard Discovery, which might have contaminated Mir's solar arrays, but it was decided to proceed and the maneuver was successfully accomplished on 6 February. The Shuttle astronauts took about 400 photos of Mir to assess meteoroid and debris damage, which despite two holes found in Mir's solar array was concluded not to be serious.

Discovery carried Vladimir Titov, the second Russian cosmonaut to fly on a Shuttle, who operated the Shuttle's manipulator while two spacewalkers tested the thermal capabilities of the United States spacesuits for long duration use on 9 February. They found that after about 4.5 hours in space, the suits' gloves did not satisfactorily protect the astronauts' hands from the cold. The two astronauts also practiced maneuvering massive objects by moving the 1,260 kg Spartan spacecraft around the payload bay. Spartan had been deployed on 7 February to conduct astronomical observations and was retrieved just prior to the spacewalk. The Discovery mission also carried a commercial Spacehab module in which a number of microgravity tests were conducted. These included testing a new contact lens material and growing protein crystals to help research cures for influenza. Another Discovery experiment demonstrated the use of a self-maneuvering robot device named Charlotte to conduct and photograph experiments inside orbiting spacecraft by remote control.

Space Shuttle Endeavour was launched on 2 March to carry out the longest Shuttle mission to date (16 days). Its goal was to use the Astro-2 payload to observe a number of active stars and galaxies using its three instruments: the 91 cm Hopkins Ultraviolet Telescope, the 38 cm Ultraviolet Imaging Telescope, and the 51 cm Wisconsin Ultraviolet Photopolarimeter Experiment. The three telescopes were aimed by a computer-controlled Instrument Pointing System that enabled the astronauts to view up to 36 stars or galaxies daily. The Hopkins telescope was able to confirm the existence of primordial helium by observations of a distant quasar.

In February, United States astronauts John Blaha and Shannon Lucid began training in Star City, Russia, for a four month mission aboard Mir in 1996. A Progress vehicle delivered about 100 kg of equipment to Mir on 17 February for use by United States astronaut Norman Thagard during his visit to the station, which began on 14 March with his launch from Baikonur. He arrived at Mir two days later, on 16 March, accompanied by Russian cosmonauts Vladimir Dezhurov and Gennadiy Strekalov. Roughly 755 kg of medical experiment equipment for use during his three-month stay was originally scheduled to have been launched to Mir in February, along with the new Spektr module. However, delays necessitated a reschedule of Spektr's launch to 20 May and its docking with Mir to 1 June. On 6 June Thagard broke the United States space endurance record of 84 days set by Skylab astronauts in 1974, and returned to Earth on 7 July on Shuttle Atlantis (see below).

Cosmonauts Strekalov and Dezhurov conducted three spacewalks between 12 and 22 May to prepare for the docking with Atlantis by partially stowing one solar array (mounted on Kristall), moving another from the Kristall module to the Kvant-1 module, and repositioning docking equipment to allow the Kristall module to be moved on 27 May to a different port so that the Spektr module could be installed. A fourth spacewalk on 29 May was conducted to reposition the docking equipment to receive the 19.5 tonne Spektr module. The Spektr was launched by a Proton rocket on 20 May and docked successfully with Mir on 1 June. After again moving the docking equipment on 2 June, the cosmonauts moved Spektr to its final position on 3 June. One of Spektr's solar panels did not unfurl properly when commanded to do so on 5 June, but this did not delay preparations for the docking mission. On 18 June, Kristall was moved to the former Spektr port, allowing Space Shuttle Atlantis to dock with Mir on 29 June (see below). Mir's final building block, the Priroda module, was to have been launched this year but has been delayed until the spring of 1996.

Space Shuttle Atlantis lifted off from the Kennedy Space Center on 27 June with the Mir crew replacements, cosmonauts Anatoliy Solovyev and Nikolai Budarin. The docking maneuver followed the pattern set in February by Shuttle Discovery, approaching Mir from below and closing with Mir at the extremely slow rate of 3 cm per second. Docking was completed successfully on 29 June, and after five days of joint physiological experiments and tests conducted by the international crew, departed on 4 July with astronaut Norman Thagard and cosmonauts Strekhalov and Dezhurov. It landed at the Kennedy Space Center in Florida on 7 July. One of the mission's main achievements, in addition to its historic importance for international cooperation in human space flight, was the transfer of tonnes of supplies and hardware between the two vehicles.

The scheduled 8 June launch of Space Shuttle Discovery to place a Tracking and Data Relay Satellite (TDRS) in orbit to replace the one lost on the Challenger in 1986 was delayed to 13 July. Woodpeckers had drilled about 135 holes in the external propellant tank's insulation while the vehicle was on the pad awaiting launch, requiring NASA to return Discovery to the Vehicle Assembly Building for repairs. The flight was distinguished by two new features: it marked the first flight of the redesigned main engine (see below) and the first use of NASA's new, heavily computerized mission control centre in Houston. The old centre controlled the more critical takeoff and landing operations; the new centre was used to control only orbital operations. It is being phased in gradually during seven Shuttle flights, after which the old centre will be retired. The new centre will be able to operate both the Shuttle and ISSA for approximately $30 million per year less than the current centre costs to operate only the Shuttle. The Discovery launch also featured the fastest turnaround to date between Shuttle launches; it took off only six days after Atlantis landed following the historic rendezvous with Mir.

Shuttle Endeavour, originally scheduled for launch on 5 August, was delayed because of concern about minor damage to solid-booster nozzle O-ring seals on the two previous Shuttle launches: Atlantis on 27 June and Discovery on 13 July. The problem was solved by replacing the rubber insulation adjacent to the seals to eliminate air pockets, and after additional delays due to Hurricane Erin and problems with one of the orbiter's three fuel cells, Endeavour was finally launched on 7 September. The crew conducted a second test of the 1,935 kg Wake Shield Facility to evaluate its ability to create a super-high vacuum for fabricating high quality electronic components by vapour deposition, but due to control problems with the deployed Wake Shield, it was only possible to manufacture four of the seven planned film samples. The crew also deployed and retrieved the Spartan-201 science satellite that collected data on the solar wind and the Earth's upper atmosphere, tested glove heaters and an improved cooling system for spacesuits (both of which proved completely satisfactory), and checked out tools and other equipment to be used in assembling the space station. Spartan 201's data were coordinated with simultaneous transmissions from the Ulysses spacecraft (see below).

The launch of Shuttle Columbia was also delayed, first by the same concern about booster nozzle O-ring seals that delayed Endeavour, and subsequently by a leaky fuel propellant valve in one of the main engines, bad weather associated with Hurricane Opal, an electronics failure during the fourth countdown, bad weather on several subsequent attempts, and lastly due to a scheduling conflict for use of the range equipment at Cape Canaveral Air Force Station, which at the time was needed for an Atlas launch of a Navy UHF communication satellite. The 16 day flight was finally launched on 20 October, on the seventh try (a new record), to conduct over 40 experiments aboard the United States Microgravity Laboratory's second flight, a 16 day mission.

On 14 July, NASA signed a $54 million contract with Spacehab for four cargo carrying modules to be installed in Shuttle cargo bays for Mir missions in 1996 and 1997. The modified Spacehab research modules will be loaded with food, clothing, spare parts, and science experiment equipment for the United States astronauts who will remain aboard the Mir station.

The Euro-Mir 94 mission (see 1994 report) ended on 3 November 1994 with the return to Earth on a Soyuz TM-19 of ESA cosmonaut Ulf Merbold and Russian cosmonauts Yuri Malenchenko and Talgat Musabayev. The longest Euro-Mir mission began on 3 September 1995 with the liftoff of ESA astronaut Thomas Reiter (Germany) from Baikonur on Soyuz TM-22, with Russian cosmonauts Sergei Avdeev and Yuri Ghidzenko. During Reiter's scheduled 180 day stay aboard Mir, Reiter plans to conduct 41 European science experiments. On 20 October, he performed the first spacewalk by an ESA astronaut. During the five hour spacewalk, he installed equipment for external astrophysics experiments. He will undertake another in January. Over 350 kg of ESA research equipment had been delivered to Mir by a Progress supply flight in July; an additional 58 kg will be delivered in December.

On 9 January, cosmonaut Valeri Polyakov, a medical doctor, broke the long-term endurance record for space travel (365 days). He logged the longest stay in space, 438 days, before returning from Mir to Earth on 22 March.

An agreement was signed on 12 September by NASA and the Space Transportation Association (United States) to conduct a study on space tourism. The study, titled "Establishing a United States Space Tourism Business," is designed to define the actions needed by the private sector and the research and development needed to be undertaken by the government to establish and maintain a viable space tourism market. Results of the study, to be completed in mid-1996, are expected to help shape decisions on the commercial successor to NASA's X-33 advanced technology demonstrator.

V. SPACE EXPLORATION

A. Astronomy and Astrophysics

The French balloon-borne Pronaos telescope, launched in September 1994, was recovered after its mission of observing interstellar clouds and dark areas for cosmologic fluctuation studies. It is being refurbished for relaunch from Fort Sumter (United States) in May 1996, when the payload will again be the 2 m Multiband Photometric System. A Heterodyne Spectrometer is planned for launch in 1997.

Processing of all data from Europe's Hipparcus spacecraft was completed in 1995. The final product is documentation of the spacecraft's observations of 118,000 stars, including identification and measurement of a number of new double and variable stars, with better accuracy than originally specified. These data will be circulated to the programme's 400 Principal Investigators in January 1996.

Europe's first infrared astronomy satellite, the $600 million, 2.2 tonne Infrared Space Observatory (ISO), underwent successful satellite and instrumentation integration testing in May. It is scheduled for launch aboard Ariane in November. The spacecraft's telescope, to be cooled to a temperature of -270 Celsius, will study infrared phenomena in the universe from a 1,000 x 70,000 km elliptical orbit.

Testing of ESA's 1,850 kg Solar Heliospheric Observatory (SOHO) progressed on schedule this year, including successful completion of ground-segment compatibility checks. After its launch by an Atlas 2AS in November, SOHO will be placed at the L-1 Lagrange libration point between the Sun and the Earth (1.5 million km from Earth), where the gravitational forces of the two bodies are equal and opposite. Its 11 ESA and NASA instruments will study the Sun's energy sources and the solar wind.

The Integral payload programme was approved by ESA in May, despite withdrawal of the United Kingdom from the project due to lack of funds. Phase-B prime contractor Alenia Spazio began work in May; CNES established a project team in Toulouse for the spectrometer; and Russian approval of the Proton launch is in process (ESA approval was secured in March). Operation of another cooperative program, the Russian Granat spacecraft launched in December 1989 carrying the French Sigma telescope, was extended through 1995 by French financial support of the Evpatoria ground station. Beginning in October, the spacecraft scans the full sky every six months, generating a complete catalogue of gamma-ray sources.

Development work continued this year on the four tonne X-Ray Multi-Mirror (XMM) spacecraft, the second cornerstone of ESA's Horizon-2000 programme (see 1994 report). Phase B-1 was completed in June, with testing on mirror module demonstration models exceeding their design requirements, and an Announcement of Opportunity for Survey Scientists was released in April.

NASA announced in February that it had modified the X-ray spectrometer originally planned for the Advanced X-Ray Astrophysics Facility (AXAF) to fly on Japan's Astro-E satellite, scheduled for launch by the Institute for Space and Astrophysical Science in August 1999. The original version of the instrument had been deleted from the AXAF mission last year as a budget reduction measure. India's IRS-P3 polar orbit satellite, to be launched in January 1996 (see above), will also carry an X-ray astronomy payload to measure the characteristics of high-energy X-ray sources.

B. Plasma Physics

The first system validation test of ESA's four 1,200 kg Cluster spacecraft, part of the joint NASA/ESA Solar Terrestrial Science Programme, was successfully concluded in April. Thermal testing is also complete, and interchangeability among the four spacecraft was demonstrated. The flight acceptance review was conducted on 1-2 June, and the spacecraft were shipped to Kourou in August. Launch on the maiden flight of Ariane-5 has been delayed by a number of factors (see above), and is now scheduled for April 1996.

C. Solar System Exploration

Pioneer 11 (United States) was finally shut down on 1 October after 22 years and 6.5 billion km of exploring the solar system and beyond, due to loss of directional control and reduced power output from its radioisotope power supply. Its companion spacecraft, Pioneer 10, continues to return data that may be helpful in determining the location of the heliopause. The two Pioneers were launched in 1972 and 1973, respectively.

On 12 March, Ulysses, launched in October 1990, crossed the solar system's ecliptic plane during the summer of 1994, making its closest approach to the Sun at about 200 million km and completing a study of the electron content of the solar corona. Among its principal findings: the solar wind issues from the south pole at about 800 km/sec, twice as fast as from the Sun's equatorial region. This summer, the spacecraft flew over the Sun's north pole, reaching its northernmost latitude of 80.2 degrees on 31 July. Data were coordinated with measurements made by the Spartan-201 instrument flown aboard Shuttle Endeavour in September. All of Ulysses' systems and instruments continue to operate normally.

The 339 kg Jupiter atmospheric probe was successfully released from Galileo as scheduled on 12 July. It will reach Jupiter on 7 December and plunge into the big planet's atmosphere at about 47.3 km/sec, after which it is expected to transmit data from its seven instruments back to the mother Galileo spacecraft for about 75 minutes before being destroyed by high pressure and heat at a depth of about 650 km in Jupiter's atmosphere.

A five minute burn of the mother spacecraft's 400-N thrust main engine on 27 July, following a two second "wake-up" burn on 24 July to verify its health after nearly six years in space, placed it on track for a fly-by past the Jupiter satellite Io on 7 December. A subsequent 47 minute burn of the main engine on that date will insert Galileo into a Jupiter orbit for a two year mission to study Jupiter and its satellites. On 28 August, Jet Propulsion Laboratory (JPL) engineers reported a jammed check valve in the oxidizer side of the helium pressurizing system following the five minute burn, but it is not expected to affect orbit insertion. Galileo also passed through the most intense dust storm ever measured by a space probe beginning about 28 July, collecting particles at up to 20,000 times the normal interplanetary particle rate.

On 11 October, a serious problem developed with Galileo's tape recorder, the only device on board that is able to store data collected by both the main spacecraft and the Jupiter atmosphere probe. Although it created much concern (including a call for canceling the Cassini mission to Saturn because of the recent rash of operational problems and failures on Galileo and other United States spacecraft), the recorder was finally restarted on 21 October and its operation was found to be satisfactory. One of the main problems with Galileo had been the failure of its main antenna to deploy after being launched in October 1989. However, the limiting data rate from the spacecraft's small low-gain backup antenna was subsequently increased from 16 bps to over 160 bps, allowing most of the originally planned data and images to be transmitted.

The planned programmes of several nations to explore Mars finally stabilized during 1995. The United States is developing two Mars spacecraft for the 1996 launch window: Mars Global Surveyor and Mars Pathfinder. The 820 kg Mars Pathfinder, scheduled for launch in December 1996, will land a 320-kg experiment package on the planet (including the 11 kg six-wheeled computer-controlled autonomous Sojourner microrover), using a combination of aerobraking, parachutes, solid propellant retrorockets, and four airbags. Its total cost, including the Delta-2 launch, was estimated on 12 December 1994 to be $246 million. The relay that will fly aboard Mars Global Surveyor to transmit data from the Mars 96 landers was delivered to NASA by CNES in September.

The Russian Federation's former Mars-94 project has been rescheduled for 1996. Installation of the orbiter's instrumentation began in September, but there have been delays in building the Argus three-axis-stabilized platform that will carry the German cameras and the French infrared spectral imager, and both technical and schedule concerns have been raised about the testing and integration of the spacecraft's two small soft-landing stations and its two surface penetrators. Delivery of the orbiter to Baikonur Cosmodrome is scheduled for June 1996, but if these problems are not resolved it is possible that the project may be cancelled.

The 1998 Mars Together mission of the United States and the Russian Federation was cancelled in May, and the Russian decision to launch Mars-98 on a Molniya rather than the larger Proton necessitated cancelling the French balloon-borne instrument package. NASA also had to delete from its 1998 Mars Global Surveyor-2 one of the two original Mars Surveyor instruments not aboard Mars Global Surveyor-1 (the infrared radiometer or the gamma-ray spectrometer), because of the decision that all United States Mars missions after 1996 must meet Med-Lite launcher constraints. On 21 July, the Pressure Modulated Infrared Radiometer (PMIRR) was finally chosen over the gamma ray spectrometer. Nevertheless, NASA offered to carry a Russian instrument on the Mars Global Surveyor-2 spacecraft, allowing this mission to be called Mars Together, but Russia's financial constraints may postpone any Mars Together mission until the next century.

A $92 million contract for Mars Global Surveyor-2, covering both the orbiter (scheduled for launch in December 1998) and the lander (to be launched in January 1999), was issued by NASA to Lockheed Martin on 20 March.

Testing of ESA's Huygens probe, planned to be released for a landing on Saturn's moon Titan by the Cassini spacecraft, was conducted at Kiruna, Sweden, on 14 May. A balloon launch of the flight model system successfully demonstrated separation and descent of the probe through the atmosphere to the ground. In September, NASA's Jet Propulsion Laboratory conducted acoustic testing of a Cassini spacecraft dynamic test model, including a model of the Huygens probe and a model of the spacecraft's high-gain antenna built by Italy. The NASA/ESA Cassini/Huygens spacecraft is scheduled for launch on 6 October 1997, arriving at Saturn in 2004 after gravity assist flybys at Venus in 1998 and 1999, Earth in 1999, and Jupiter in 2000.

ESA's third Horizon 2000 cornerstone mission, a cooperative comet exploration by NASA, CNES (France) and Germany, was renamed the International Rosetta Mission. Selection of payload contractors for the landers, the NASA/CNES Champollion and the German Roland, was expected to take place in late 1995; the system design and the payload contractor for the orbiter are expected to be approved by ESA in February 1996. NASA will provide Deep Space Network support and scientist participation in the orbiter payload.

In February, NASA announced plans for a New Millennium programme aimed at radically shrinking the size and cost of both planetary and orbital science spacecraft while at the same time increasing their performance and capability. Initial funding in fiscal year 1996 (which began in October 1995) was set at $30 million, with follow-on funding of $30 million and $50 million respectively for the next two years. Key technologies are likely to be digital electronics, lightweight materials, near-autonomous spacecraft operation, and advanced sensors. NASA's project management will also change significantly, featuring partnerships with industry, academia, and other United States federal agencies.

The project was initiated by JPL in April, generating over 230 proposals from industry and academia for technology research in communications, autonomous spacecraft and ground systems, microelectronics, modular architectures and multifunctional systems, lightweight instruments, and microelectromechanical systems. These were narrowed down to 23 finalists, and on 19 September, Spectrum Astro was selected for the first New Millennium award. The spacecraft is to be launched in 1998 aboard a Lockheed Astria-2 on a 14-17-month mission to study comet Faye and two asteroids, one of which will probably be Cuno. The primary goal of this first project, however, is to develop and demonstrate some of the new technologies; specifically, a new multi-kilowatt solar cell and array concept and a primary electric propulsion system using xenon (see below). If they are sufficiently mature by then, the 340 kg spacecraft will also demonstrate laser communications, solid-state X-band and Ka-band radio transmitters, and lithium ion batteries.

NASA made its first formal Discovery series award on 28 February to Lockheed Missiles and Space Company (now Lockheed Martin) for a Lunar Prospector. The contract, worth $59 million, calls for launch on a Lockheed Astria-2 in June 1997. The spacecraft will carry five sensors to study the composition of the Moon from low orbit, including a search for ice in the south polar region (see below). The Lockheed proposal was one of 28 considered by the agency for missions having a maximum cost of $280 million, including launch and operations. Three runners-up were also selected and granted $1 million awards to continue their studies in competition for the second Discovery mission, which was to have been selected in late 1995. The three competitors are a Hughes Space and Communications Company proposal for a Venus Multiprobe Mission to launch 16 probes into Venus's atmosphere; a Martin Marietta proposal for a Suess-Urey Solar Wind Sample Return Mission; and a Martin Marietta Stardust Mission to return samples collected from the tail of Comet P/Wild 2 to Earth for analysis.

It was announced on 7 October that a re-examination of the lunar radar survey data collected by the United States Clementine spacecraft in 1994 suggests the possibility that water ice exists in deep, permanently shaded craters in the Moon's south polar region. Confirmation of this will come with the launch of the Lunar Prospector in 1997 (see above).

The mission objective of the Near Earth Asteroid Rendezvous (NEAR) spacecraft, which was transferred into the Discovery programme after the project's origination in

December 1993, was changed this year to incorporate a close fly-by (1,200 km) of asteroid 253 Mathilde in June 1997. The change involved a velocity penalty of only 57 m/sec, and will provide the first opportunity to study a C-class asteroid. NEAR will also rendezvous with asteroid 433 Eros in December 1998 and will remain in a 30 km orbit around it for one year. Eros is one of the largest near-Earth asteroids (36 x 15 x 13 km). NEAR's planned launch in February 1996 (the first Discovery-series launch) will be the culmination of a remarkably short development, integration, and test time (26 months) by the Applied Physics Laboratory (United States). The spacecraft will measure Eros's physical and geological properties; it is expected that these data will be used to help clarify the relationships among comets, asteroids, and meteorites and advance our understanding of the processes which took place in the early Solar System.

The NEAR mission may also be used to gather data for a subsequent Japanese project, Muses-C, which is being developed by the Institute of Space and Astronautical Sciences (ISAS) for launch to asteroid Nereus in 2002. Muses-C will land on Nereus in 2004 and return a sample of the asteroid to Earth in 2006. NEAR's potential role, which is still being discussed, would be to maneuver into contact with asteroid Eros at the end of its mission there, to provide operational experience to ISAS on an asteroid encounter.

D. Search for Extraterrestrial Intelligence (SETI)

The SETI Institute (United States) initiated in January a four month scan of 200 stars using the 65 m Parkes radiotelescope in New South Wales, Australia. The search is part of the privately financed institute's Project Phoenix, whose goal is to survey 1,000 stars for signs of extraterrestrial intelligence by 2000.

VI. TECHNOLOGY ADVANCEMENT

A. Propulsion

1. Earth-to-Orbit Propulsion

Preliminary ground tests of an upgraded Space Shuttle Main Engine (SSME) on 10 and 28 January indicated specific impulse that was 1.0 to 1.5 seconds lower than expected. The shortfall was corrected by re-routing the liquid hydrogen fuel flow to improve its cooling effectiveness. One of the upgraded engines flew successfully during Discovery's mission launch on 13 July, and was found to be in excellent condition during post-flight inspection. The modifications, which cost NASA about $1 billion, include a new Pratt & Whitney high-pressure oxygen turbopump and a redesigned Rocketdyne hot gas manifold. The new pump generates 19,300 kW of mechanical power and spins at 395 revolutions per second. It has only seven welds, all accessible to inspection, as compared with 300 in the former pump. Following their maiden flights, the new pumps are to be reused 10 times without removal for major inspection, in contrast to the single-flight limit of the previous oxygen pump. New hydrogen pumps and an improved combustion chamber are planned for initial flights in 1997.

In August Lockheed Martin (United States) announced plans to flight test a Rocketdyne aerospike rocket engine aboard an SR-71 supersonic aircraft during the spring of 1996. The aerospike concept, originally developed by Rocketdyne as a contender for use on the Space Shuttle, automatically adapts to changes in atmospheric pressure during ascent through the atmosphere. It is being evaluated by Lockheed Martin for use on the X-33 Advanced Technology Demonstrator in NASA's Reusable Launch Vehicle programme (see above). The flight tests will cover the speed range from Mach 1 to Mach 1.5 at altitudes from sea level up to the SR-71's flight ceiling.

Also in August, the United States consolidated its civil hybrid booster rocket development efforts into a $50 million joint government-industry-university Hybrid Propulsion Development Program. The goal of the four year program is to conduct ground tests late in 1998 or early in 1999 on a flight-type 1.1-MN hybrid booster rocket motor using liquid oxygen and solid hydroxyl-terminated polybutadiene (HTPB) fuel.

The first long duration (280 second) test of Ariane-5's mainstage cryogenic engine was conducted at Kourou on 17 November 1994. The second and third engine tests were completed by January. The first 600 second firing of the full main stage, attempted on 30 May, was shut down by the vehicle's computer after five seconds due to improper programming of the computer's allowance for the time delay between starting the hydrogen and oxygen turbopumps. A subsequent 590 second main-stage firing on 16 June was successful, as was a 21 July firing of the solid propellant booster rocket. Subsequent problems with the stage, however, have necessitated delaying Ariane-5's maiden flight until April 1996 (see above).

In July, the first Russian rocket engines to be shipped to the United States for potential use on United States launch vehicles were received by Pratt & Whitney and Aerojet. On 25 October, Pratt & Whitney test-fired an oxygen-kerosene Energomash RD-120, currently in production as the second stage of the Zenit launcher, on its West Palm Beach test stand. Pratt & Whitney has offered the 830-kN thrust RD-120, modified to the RD-120M configuration for use as a booster, to American Space Lines for the new X-34 partly reusable launcher currently being developed with joint NASA-industry funding (see above). On 14 July Aerojet received from the Samara State Scientific and Production Enterprise two 1.5-MN-thrust NK-33s, the oxygen-kerosene engines originally developed and built for the Soviet Union's Moon launcher over 25 years ago. One of the engines will be tested later this year at Aerojet's Sacramento facility to verify its performance; the other will be modified to meet the launch configuration requirements of Lockheed Martin's Atlas launcher.

Pratt & Whitney also announced on 13 June the consummation of an agreement with France's Société Européenne de Propulsion (SEP) to cooperate in the design, development, and marketing of engines for launch vehicles and missiles. SEP had previously announced cooperative agreements with Volvo Aero Corporation (Sweden) and Daimler-Benz Aerospace (Germany) to conduct research on future large cryogenic rocket engines. On 24 August SEP and NII Khimmash (Russia) conducted a 118-second test of the Chemical Automation Design Bureau's (Russia) RD-0120 2-MN-thrust hydrogen-oxygen engine, which powers the Energia vehicle's core stage. The test was part of a joint Russian-European Cooperative Rocket Engine Demonstration programme (RECORD), financed primarily by the European Union, with the goal of evaluating the RD-0120 (sometimes designated rd-120) for future reusable launchers.

In August, Lockheed Martin, which holds the United States license for use of the 4-MN thrust throttleable RD-180 on Atlas launchers or their derivatives, selected Pratt & Whitney over Rocketdyne as the licensee (to Energomash) for development of that engine, which is a half-scale derivative of the Zenit's RD-170 booster powerplant. Lockheed Martin plans to select in December either the RD-180, the NK-33, or a new Rocketdyne engine for both a new version of the commercial Atlas and Lockheed Martin's candidate for the new United States Air Force EELV (see above). McDonnell Douglas, another EELV Phase 1 contractor, is considering a number of Russian engines: the NK-33, the RD-170, the RD-180, and a quarter-scale RD-170 designated the RD-190. Japan is also considering use of the NK-33 to improve the performance and reduce the cost of the H-2 launcher's planned upgrade (the H-2A) by replacing the present solid-propellant boosters with liquid-propellant ones (see above).

On 20 October, NASA Administrator Daniel Goldin announced plans for setting up a programme to develop a new generation of low-cost United States rocket engines comparable in operability, cost, and reliability to modern aircraft jet engines. Although his announcement focused on post-X-33 propulsion requirements, it was consistent with a new policy issued by NASA on 29 September that forbids the use of United States federal funds for foreign development of Reusable Launch Vehicle propulsion technology. Mr. Goldin cited the Aerospike engine being developed by Rocketdyne (United States) for Lockheed Martin's version of the X-33 technology demonstrator as an example of a commendable new United States approach to propulsion (see above).

India announced on 6 March the signing of a purchase contract with Russia for cryogenic engines to be used on the first seven launches of the Geosynchronous Satellite Launch Vehicle (GSLV), beginning in 1998. The new contract represents an increase from four engines stipulated in the previous contract. India plans to have its own cryogenic engine design operating by 2000. The contract also includes two full-scale engine mock-ups, one of which is scheduled for delivery to India in January 1996 for use in ground tests of the GSLV.

2. In-Space Propulsion

The United Kingdom's Royal Ordnance Facility began tests on a 400-N thrust hybrid rocket engine for orbit transfer of small satellites. The hybrid rocket concept, which was first flight tested over 50 years ago, uses a solid fuel and a liquid oxidizer. Unlike solid propellant orbit transfer rockets, a hybrid rocket can be stopped and restarted several times. The Centre for Satellite Engineering Research and Surrey Satellite Technology Ltd. plan to use the hybrid aboard a 300 kg spacecraft scheduled for launch in 1996.

Studies conducted in 1994 and 1995 by the International Space Technology Institute, a joint venture of companies in France, the Russian Federation and the United States, indicate that electric propulsion, as embodied in stationary plasma thrusters, are not only useful for station-keeping functions but could also facilitate orbit transfer missions beyond the capability of chemical rockets; e.g., asteroid sample returns.

The Electric Propulsion Experiment (EPEX), a magnetoplasmadynamic (MPD) arcjet propulsion system flight test, was conducted aboard Japan's Space Flyer Unit (SFU-1) launched by H-2 in March. The test of the repetitive pulse hydrazine thruster was the first to be conducted in space at a power level above 200 kWe.

Germany's 15-mN RIT-10 thruster for satellite station-keeping reached the flight qualification stage in 1995. Qualification is expected to be completed in 1996. The second-generation thruster has a design life of 15 years. A 50-mN thruster is currently in development for primary propulsion of deep space missions, in cooperation with the United Kingdom.

The Fakel SPT-100 thruster used on the Russian Gals satellites underwent a 7,000 hour life test that met Western qualification standards. The eight thruster assemblies used on the Gals and Express spacecraft provide both north-south and east-west station-keeping. Current tests by the Research Institute of Applied Mechanics and Electrodynamics of the Moscow Aviation Institute (RIAME-MAI) on a modified design, SPT-100N, demonstrated efficiency increases of 3-7 per cent and 50 per cent decreases in plume divergence. RIAME-MAI has also developed and tested for NASA a laboratory model of a 100-kWe lithium MHD thruster, achieving an efficiency of 35 per cent at a specific impulse of 3,000 seconds.

The Ukrainian electric propulsion development programme continued in 1995 with tests of an ammonia thruster, closed electron drift thrusters, and non-space applications of electric thrusters. The ammonia thruster demonstrated high thrust-to-power capability (4 kWe/N), and the closed electron-drift thruster achieved efficiencies up to 55 per cent at 17 kWe/N, along with longer lifetimes than SPT thrusters. Non-space applications of these devices include ionic surface cleaning, deposition of coatings, neutralization of hazardous waste, and ultrafine powder production. Electric thruster technology is also being explored for high-efficiency thermionic power conversion.

The first New Millennium spacecraft, selected by NASA on 19 September (see above), will use a primary electric propulsion system for the first time. The solar electric thruster, being developed by Hughes Electron Dynamics Division (United States), will develop 0.09 N thrust at a specific impulse of 3,000 sec. The entire power/propulsion system is to weigh only 135 kg, plus 40 kg of xenon propellant. It will increase the velocity of the 340 kg spacecraft (including the fully fueled power/propulsion system) by 3.8 km/sec.

3. Hypersonic Propulsion

On 10 November 1994 Aerospatiale (France) successfully tested a 20 cm diameter supersonic combustion ramjet (scramjet) at simulated flight speeds of Mach 6. The test was part of the four year, $96 million French hypersonic engine research programme Prepha.

In January, the United States Air Force withdrew from the joint NASA/United States Hypersonic Systems Technology Program (HySTP), which had been created after the demise of the United States National Aerospace Plane (NASP) programme. The remaining 1995 funds ($35 million) were spent on generic hypersonic research. NASA followed suit on 9 February, cancelling the originally planned scramjet flight test on a Minuteman missile and folding the HySTP effort into the agency's basic aeronautics research programme.

B. Power

The first flight-ready solar panels for Motorola's 66 spacecraft Iridium communication satellite constellation were shipped in 1995 by Lockheed Martin. The panels employ gallium arsenide solar cells which are welded, rather than soldered, into the panels, cutting assembly time for the 600 W panels (two per spacecraft) from two weeks to two days. It also marks the first time that mechanical drives derived from military spacecraft have been used on commercial satellites. The Applied Solar Energy Corporation's gallium arsenide cells operate at 18 per cent efficiency compared with standard silicon cells' 12 per cent, and are scheduled to be superseded soon by 21 per cent efficient cascade cells.

The power system for the first solar electric New Millennium mission contracted by NASA on 19 September (see above) will be a 2.6 kW solar array developed by the United States Ballistic Missile Defense Organization (BMDO) and the United States Phillips Laboratory. It uses linear concentrators to focus sunlight on gallium arsenide photovoltaic cells, which develop 26 per cent efficiency. 2.4 kW will be used to drive the xenon thruster (see above); the remaining 200 W are to be used for internal power needs.

In October, the first space demonstration of a photovoltaic concentrator array was to have been conducted aboard the Multiple Experiment Transporter to Earth Orbit and

Return (METEOR), originally planned for launch in August by the first Conestoga. The failure of the Conestoga on its 24 October launch attempt (see above) and the destruction of the payload precluded carrying out the demonstration. The array, whose development was supported by NASA-Lewis and the United States BMDO, uses advanced linear refractive element concentrators, gallium arsenide cells, and a unique deployment structure. Flight qualified hardware was fully developed only six months after concept definition.

Results of the joint NASA-Lewis/United States Air Force satellite experiment Photovoltaic Array Space Power Plus Diagnostics (PASP-Plus), released in July after nearly a year in orbit, demonstrated extremely low performance degradation and verified predicted off-pointing losses for mini-dome refractive solar cell concentrators. PASP-Plus data on indium phosphide cells also indicated marked superiority to planar gallium arsenide and silicon cells.

To meet the challenges of the new United States small-spacecraft initiatives, power system development began this year to focus on low mass and low cost. NASA and the DOD initiated development of a joint solar concentrator array named Scarlet, which is planned to power flight tests of Russian Hall Effect electric thrusters. NASA and the Department of Energy (DOE) also began this year to investigate improved radioisotope power conversion systems for potential deep-space missions such as Pluto Express. Candidate conversion systems include Stirling cycle, thermophotovoltaics, and alkali metal thermal-to-electric conversion (AMTEC).

A new high-efficiency solar cell based on advanced silicon technology was developed this year for future ESA missions such as the Rosetta cometary spacecraft. The new cells have an efficiency of 27 per cent in deep space (10 per cent Sun intensity, 100° Celsius) compared with the 20 per cent available with current technology.

In December 1994, NASA's Lewis Research Center conducted the world's first test of an integrated solar dynamic power system in a simulated space environment. The system employs thermal energy storage and Brayton power conversion; it developed 2 kWe net power at more than 15 per cent efficiency for over 169 hours during 75 simulated orbits. At meetings in March and June, participants recommended development of a 10 kWe solar dynamic power system by 2000 and a 2,500 kWe system by 2010. Joint efforts on the 10 kWe system had been approved by the United States and the Russian Federation on 3 September 1993.

NASA initiated a new study in April to re-examine the economic viability and commercial potential of space-based solar power systems, including delivery of power to other orbiting platforms such as space stations and space industrial parks. The rationale for the new study is that much new technology has become available in the 15 years since NASA's previous study of the concept. Moreover, the global economic situation and energy demand scenarios have changed significantly, and there are new environmental issues to be addressed.

Future Russian Federation planning, announced in July, includes a 10 GWe lunar power station using indigenous amorphous silicon. The manufacturing concept is based on Russia's current automated production line, which is producing amorphous silicon at a capacity of about 1 MWe/year. NIITP and TsNIIMash completed this year a preliminary study of the lunar production base, including an Earth-Moon-Earth transportation infrastructure based on single stage vehicles able to carry 60 tonne payloads to a 250 km orbit.

Japan announced in July the successful completion of Kansai Electric Power Company's wireless power transmission experiment, in which a 2.45 GHz beam transmitted 5 kWe over a distance of 50 m. A 1 W functional model of a solar power satellite system was also demonstrated. It included solar arrays, a microwave power generator, a transmitting antenna, and a rectenna; retrodirective beam control is currently being added. In May, successful tests of the Miura-ori deployment mechanism and a high voltage solar array were conducted aboard the Space Flyer Unit launched by an H-2 vehicle in March 1994.

In May, the United States DOE solicited bids for a programme called Nuclear-Space Technology Applications and Research Teams (N-START) to conduct a broad range of research and technology activities.

C. Automation, Robotics, and Teleoperators

Tests of the Marsokhod rover built by Lavochkin Association (Russia) were conducted by McDonnell Douglas (United States) inside Hawaii's Kilauea volcano for six days beginning on 13 February. The first three days simulated a Mars mission; the second three, a lunar mission. The test data and images were transmitted to researchers and students worldwide via the Internet, and 60 students at NASA's Ames Research Center in California took turns guiding the robot by remote control during the lunar mission simulation.

D. Materials and Structures

Several important new materials and structures test facilities became operational at Wright Laboratories (United States) this year. The Combined Environment and Subelement Acoustic Chambers (CEAC and SEAC) can conduct thermoacoustic tests at sound pressures of up to 175 dB. The SEAC can accommodate structures of up to 30 x 45 cm in size at temperatures to 1,400° Celsius and thermal fluxes up to 60 W/sq. cm. The CEAC's 1.2 m test section accommodates actively cooled structures at temperatures up to 1,650° Celsius and thermal fluxes of up to 40 W/sq. cm. The Actively Cooled Structures Laboratory (ACSL) can condition test panels from cryogenic temperatures to 450° Celsius at pressures up to 300 atm, with thermal fluxes in the small test section (2.5

x 10 cm) up to 1.6 kW/sq. cm and up to 240 W/sq. cm in the large test section (30 x 61 cm).

A Titan-4 second stage nozzle extension skirt liner fabricated from a new heat-resistant asbestos-phenolic composite material failed on 31 July, about 28 seconds before the end of a planned 258 second ground test. Temperatures behind the ablative liner were measured at 540° Celsius, 110 degrees higher than predicted. The failure delayed launches of two Titan-4s on which nozzle skirt liners manufactured from the new material had been installed, so that they could be replaced with spare skirt liners made from the old resin-impregnated asbestos-phenolic material.

Construction of the first full-sized Al-Li 2195 (aluminum-lithium alloy) external tank for the United States Space Shuttle was begun on 28 June. It is scheduled for delivery in September 1997 for use on the first Shuttle flight in the space station deployment sequence, currently planned to be launched in December 1997. The new tank is 3,400 kg lighter than the current Al-2219 (aluminum alloy) tank, a weight reduction needed for the Shuttle to deploy key space station elements to a 51.5 degree orbit. A shorter full-diameter test tank is being fabricated for delivery to NASA in December for testing to be completed by May 1996.

A new method for rapid construction of satellites was announced by Composite Optics, Inc. (United States) on 29 August. The fully automated technique, called Short Notice Accelerated Production Satellite (SNAPSAT), uses computer-controlled water jets to cut spacecraft chassis components from laminates of a polymer matrix composite sheet. It has been used to build the bus for Los Alamos National Laboratory's Fast On-orbit Recording of Transient Events (FORTE) satellite, which will detect nuclear explosions from space after its launch next March. The process not only cut the time required to build and test FORTE's chassis from 30 to 10 weeks, but also provided a lighter structure able to carry higher loads.

Efforts undertaken this year by ESA's Technology Research Programme and General Support Technology Programme focused on pathfinder technologies such as extreme precision pointing (i.e., nanorads) and large (over 10 m), extremely low mass antenna reflectors (e.g., 1 kg per sq. m) requiring very low stowage volume. The French space agency (CNES) and the French space industry initiated a stability-oriented technology programme focusing on actively controlled instrument structures and the modeling and reduction of microvibrations, as represented, for example, by the Castor smart-structure experiment to be flown aboard Mir in 1996.

Japan's Space Flyer Unit (SFU), launched in March by an H-2 rocket (see below), employs a unique segmented structural configuration consisting of six payload boxes and a bus. This allows each experiment to be integrated and tested separately from all the others and from the bus systems. The structure is also unique in that it is compatible with two different space transportation systems: the H-2 which launched it and the Shuttle

Orbiter which will recover it in January 1996. The SFU also incorporates Japan's first flexible solar arrays, not only the main (30-m) panels but also an experimental array deployable in two dimensions. This array was deployed and restowed successfully. Deployable antenna structures were also demonstrated late in 1994 aboard the ETS-6 satellite launched in August of that year, and active vibration suppression testing of flexible structures was conducted on ETS-6's solar arrays from December 1994 through May 1995.

E. Sensors

Early in 1995, miniature solid-state sensors used to measure radiation in space (Radfets), originally developed by ESTEC under contract to ESA, were flown on the British STRV satellite and were selected by NASDA for use on Japan's Advanced Earth Observation Satellite (ADEOS) and in the Japanese Experiment Module (JEM) for ISSA. Studies of potential non-space Radfet use are being conducted for radioactive waste management in the United States and for treatment of cancer in two hospitals in the United Kingdom.

F. Space Research Facilities

On 2 December 1994, ESA announced an increase to three per year (from only one per year since 1992) in its purchases of microgravity aircraft flight facilities, provided commercially by France's Novespace. The French government committed its support of Novespace's purchase of an Airbus 300 this year, replacing the current Caravelle. Novespace released the following comparison of its capabilities with other microgravity test facilities:

	Caravelle*		**Drop Towers****		**Sounding Rockets**	**Recoverable Capsules**	**Shuttle (Spacehab)**
	8 exp	**1 exp**	**Zarm**	**Jamic**			
Mass (kg)	2500	250	180	1000	250	500	1400
Time	25s	25s	4.7s	9.4s	6 min.	2 weeks	10 days
Cost ($)	158,000	36,350	5,000	9,100	9,100/kg	18,200/kg	60,000/kg

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* 3-day campaign, up to 120 parabolic maneuvers

** Zarm is in Germany, Jamic is in Japan

An international recovery capsule designed to test a new heat-shield material for Earth atmosphere reentry applications was lost on 15 January when Japan's solid propellant M-3S2 launcher failed to deliver it to its planned orbit (200 x 400 km). The Express capsule was a cooperative programme led by Germany's DARA, which invested $19 million. The capsule was built by Daimler-Benz Aerospace (Germany) using a shell built by the Khrunichev State Research and Production Center (Russia). It carried Japanese and German experiments, was launched by ISAS on a vehicle built by Nissan Motors (Japan), and was to have been recovered by parachute at the Woomera Test Range (Australia) after its planned 5.5 day mission. DARA plans a reflight of Express to test the company's new Cetex heat shield material. The failure was the first for the M-3S2 launcher after seven successes. It is being succeeded by the larger solid-propellant M-5, which can orbit payloads up to 2,200 kg.

Another recovery capsule was lost when the 2 tonne Photon microgravity experiment container was dropped 100 metres to the ground from a Russian helicopter on 3 March during a storm. The capsule had been launched on 15 February from the Plesetsk Cosmodrome and was successfully recovered a few hours prior to the helicopter accident. The Photon's payload had included an ESA "Biobox," which had flown unsuccessfully aboard a Photon in December 1992, a French space agency (CNES) Ibis oven, and a German payload containing seven microgravity experiments. The three European organizations had paid Russian organizations a total of $3.1 million for the flight tests. The experiments will be re-flown on a subsequent Photon capsule mission.

Germany's 150 kg Mirka capsule was tested for both land and water recovery in September by the Central Specialized Design Bureau (Samara, Russia). The capsule, built by Kaiser-Threde and Dasa Jena-Optronik, will be launched from Plesetsk early in 1996 as a secondary payload on a Photon capsule. It will separate from the Photon after two weeks and land via parachute in Kazakhstan.

After several delays due to technical problems, Japan's 3.6 tonne Space Flyer Unit (SFU) was finally launched aboard an H-2 rocket on 18 March (see above). The $470 million retrievable space laboratory can carry up to nine separate experimental racks. It is scheduled for retrieval aboard Space Shuttle Endeavour in December by the third Japanese astronaut to fly in a Shuttle, Koichi Wakata. Japan also launched a 428 kg microgravity research payload aboard the fourth TR-1A sounding rocket from the Tanegashima Space Center on 25 August. The payload reached an altitude of 270 km, and was recovered by parachute from the ocean about 300 km downrange.

The feasibility of a noise-attenuated magnetic-bearing momentum wheel for spacecraft was demonstrated by ESTEC in March. By incorporating special electronic filters into the active magnetic suspension system, the new system reduces vibration disturbances to the spacecraft by factors of 100 to 1,000. It has been selected by Matra Marconi Space for the French technology demonstration satellite Stentor (see above), and is being considered for use by Intelsat, Lockheed Martin, Loral, and Hughes.

On 11 August, Boeing Defense and Space Group (United States) and Rocket Space

Corporation (RSC) Energiya (Russia) announced a joint venture to provide commercial and government organizations "turnkey" access to the exterior of the Mir space station for remote sensing instruments, development and demonstration of space hardware, and scientific studies. Payloads can be up to 65 cm in diameter and 120 cm long, weigh up to 100 kg, and consume up to 200 W of electric power.

G. Environmental Effects of Space Flight

During the first quarter of 1995, ESA's ESTEC laboratory initiated development of standard environmental models and assessment methods to be used by the European space industry in designing satellites to survive the debris, solar wind, and geomagnetic environment they are likely to encounter. These models, which use ESA's and the industry's on-going analyses of the space environment based on actual satellite data, minimize cost and risk and help avoid satellite over-design.

On 26 December, the third stage of a Russian Rockot launcher exploded at an altitude of 2,000 km after launching an amateur radio satellite. The explosion created a debris cloud of at least 30 fragments, which because of its high orbit will remain in space for thousands of years.

The United States National Research Council issued the results of its study, "Orbital Debris - A Technical Assessment," on 14 June. The study involved participants from the major spacefaring nations, and concluded that: 1) an international group of government, industry, and academic representatives should be formed to guide orbital debris research and data gathering; 2) that better data were needed on which to base debris mitigating efforts; 3) that an international system for collecting, storing, and distributing space debris data should be set up; 4) that spacecraft designers need a guide to help them assess debris hazards; and 5) that international discussions to draft acceptable debris reduction measures should be held.

VII. EDUCATION

A. Teaching Programmes

The 1995 summer session of the International Space University (ISU) was held at the Royal Institute of Technology in Stockholm, Sweden. Sixty students conducted the ISU's design project, "Vision 2020," to project global space activities for the next 25 years. The study took into account effects such as the end of the Cold War, the growing interdependence of civil and military technologies, government budget constraints worldwide, and the increasing emphasis on commercial developments by the private sector. The summer session was attended by over 100 students from 26 countries.

On 23 November 1994, The Aspen Global Change Institute (United States) announced the details of its Ground Truth Studies programme, begun in 1992. The Institute works with over 1,000 teachers in 38 states and five countries, whose students learn about environmental monitoring by correlating remote sensing images with field observations.

The first two awards in NASA's Student Explorer Demonstration Initiative (STEDI) went in February to student teams from Boston University, for a mission to study the Earth's ionosphere and upper atmosphere, and the University of Colorado at Boulder, to measure nitrogen oxides in the lower atmosphere. The winners were chosen from six finalists winnowed down from 98 proposals. Each mission is to cost a maximum of $4.4 million, including launch. Launches are planned for early 1997.

On 25 March, about 250 fifth grade students from nine schools in Albuquerque, New Mexico (United States) showed the results of a three month Marsville programme, during which they designed and built a town suited to Mars. Their design, sponsored by the United States Air Force's Phillips Laboratory and exhibited at Kirtland Air Force Base, consisted of 12 inflatable shelters connected by tunnels, and included models of life support systems for supplying air and water, for temperature control, and for waste management.

On 12 May, NASA launched a sounding rocket payload built by students from three Florida (United States) high schools to an altitude of 73 km. The launch, from Wallops Island Virginia, was witnessed by a group of the students who built the payload, which consisted of instruments to measure atmospheric pollution and equipment to transmit the data to scientists on the ground.

The Institute of Space Sciences and Applications was established in Toulouse, France, on 3 April to train personnel in using Earth observation, position location, and communication satellite systems. The new institute, which was sponsored by universities and government agencies in the Toulouse area to help meet the personnel skill needs of the large space companies located there, will coordinate its activities with those of the ISU in Strasbourg, France.

Students and professors at the Polytechnical Institute of Madrid, Spain, designed, built, and on 7 July launched a 47 kg UPM-Sat 1 spacecraft as a secondary payload on an Ariane rocket. The $1.7 million satellite is conducting experiments in solar energy, including performance testing of a gallium arsenide solar panel, and fluid dynamics. Work has also begun on a UPM-Sat 2 to conduct communication experiments with a store-and-forward data system.

During July, the Alpbach summer school in Austria addressed the ESA Horizon 2000+ scientific programme, focusing primarily on a Mercury orbiter and the detection of extrasolar planets.

In February, two of Japan's largest preparatory schools for students taking college entrance examinations, Nagase and Yotsuya Otsuka, began delivering student instructional material by satellite to 20 schools throughout Japan.

On 26 May, the student-run Australian Space Research Institute (ASRI) launched Ausroc-2, a 6 m long sounding rocket powered by a liquid oxygen-kerosene engine. The launch was intended to carry its payload, a television camera and telemetering equipment, to an altitude of 10 km and land the payload by parachute 25 km downrange, but a faulty helium pressure regulator limited the burnout velocity, the altitude, and the range to about half the planned levels. ASRI plans subsequent models: Ausroc-3 for 1997 and Ausroc-4, an orbit capable vehicle, by 2000.

B. Public Awareness

In November 1994, ESA initiated a technology transfer programme to stimulate the use of innovative space technology in non-space applications. Its main element is an annual Technology Catalogue produced for ESA by Spacelink Europe.

On 5 September, ESA astronaut Thomas Reiter carried 20 paintings to the Russian Mir space station to be judged by the three Mir cosmonauts. The winning painting, to be announced late this year, will remain aboard Mir permanently. The competition, titled "Ars ad Astra," was sponsored by the OURS Foundation (Switzerland). Copies of the paintings were exhibited at the 2-7 October International Astronautical Congress in Oslo, Norway.

VIII. INTERNATIONAL COOPERATION AND SPACE LAW

The Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space held its 34th session in Vienna from 27 March to 7 April 1995. The Subcommittee continued its discussion of its three agenda items: the question of early review and possible revision of the principles relevant to the use of nuclear power sources in outer space; matters relating to the definition and delimitation of outer space and to the character and utilization of the geostationary orbit; and consideration of the legal aspects related to the application of the principle that the exploration and utilization of outer space should be carried out for the benefit and in the interests of all States, taking into particular account the needs of developing countries.

With regard to the question on the definition and delimitation of outer space, a "Questionnaire on possible legal issues with regard to aerospace objects" was finalized. The Subcommittee agreed that the purpose of the questionnaire was to seek preliminary views of States members of the Committee on the Peaceful Uses of Outer Space on various issues relating to aerospace objects. It was hoped that the replies to the questionnaire would provide a basis for the Legal Subcommittee to decide how it might continue its consideration of the agenda item. Some progress was also achieved on other matters on the agenda. More details can be found in the report of the Subcommittee in United Nations document A/AC.105/607.

On 15 December 1994, the European Court of Justice ruled that the EU has the legal right to negotiate service-related space issues such as launch vehicle sales on behalf of the Union's member nations. That right had been contested by several of the individual nations.

On 23 December 1994, Russian Space Agency (RSA) director Yuri Koptev and Indian Space Research Organization (ISRO) chairman Krishnaswamy Kasturirangan signed a comprehensive cooperative agreement covering broad areas of space science, use of both space and ground-based facilities, meteorology, environmental monitoring, remote sensing, communications, life sciences, space medicine, materials processing, and human space flight research. The new agreement also covers military and technical cooperation through 2000.

On 1 January, Finland became the 14th member of ESA, bearing a 1.73 per cent share of the agency's science programmes and administration. Finland also subsequently became the 15th member of the EU.

Pursuant to decisions reached in 1994, in January 1995 Inmarsat began building a capital funding base for a new sub-organization, known as Inmarsat-P, that will establish, own and operate a global, personal telephone communication satellite network. Original system cost is estimated to be US$ 2.6 billion. In January the first capital subscriptions produced about $440 million from the Americas and Europe, about $150 million from a small group of Middle Eastern countries, about $670 million from Asia and the Far East, and $150 million from the Inmarsat Organization, exceeding half the total system capital required. On 7 April, Inmarsat's council approved a new policy allowing the United Nations free access to its satellite constellation for use in disaster relief operations. Up to eight mobile ground stations will be able to use the system at no charge for renewable three week periods upon request by the United Nations. In July, Ghana joined Inmarsat as its 79th member nation.

A new International Space Science Institute (ISSI) was founded in Bern, Switzerland, on 6 November 1995 with an international workshop on the outer reaches of the solar system. The focus of the institute is on data from international missions devoted to the physics of the Sun, the solar wind and other space plasma, comets, and interactions between the Sun and Earth. The ISSI is funded by ESA, the Swiss and Bern canton governments, and the Swiss firm Contraves.

Six major telecommunications companies representing ASEAN created a new company on 24 January to provide a single point of contact for multinational companies involved in both satellite and terrestrial communications networks. The six ASEAN nations are the Philippines, Indonesia, Singapore, Malaysia, Thailand, and Brunei. On 14 February, companies in three of these nations (the Philippines, Indonesia, and Thailand) also agreed to set up a joint system to deliver mobile satellite communication services. The new company, the Association of South East Asian Nations Cellular Satellite System (ACES), completed equity financing of $150 million on 18 May, and on 6 July contracted with Lockheed Martin to deliver two A2100 satellites in 1998. The $650 million ACES system will employ dual mode hand-held telephones compatible with both ground-based cellular systems and the two GEO satellites. The telephones are to be developed and built by Ericsson (Sweden) under a $225 million contract signed in July.

On 30 January the governments of China and the United States reached a bilateral accord extending their agreement relating to launch services. The original agreement, entered into in 1988, expired in 1994. The new agreement provides that China's Great Wall Industries may launch up to 15 geostationary satellites through 2001, including 11 new spacecraft and 4 already under contract. Under the terms of the agreement, China will price its launches within 15 percent of Western companies' charges for comparable payloads.

In February 1995, Japan's Ministry of Posts and Telecommunications announced plans to accelerate deregulation of Japan's telecommunication industry by permitting more transborder satellite broadcasting. The ministry was expected to grant several licences to Japanese-based cable companies to take direct feeds from foreign television broadcasters for programme distribution through Japanese cable systems. Kokusai Denshin Denwa Co. Ltd. (KDD) is permitted to establish a new satellite receiving facility in Tokyo to meet growing demand from broadcasters for trans-Pacific links. In May, KDD announced receipt of approval from the Japanese Ministry of Posts and Telecommunications to operate an international television relay service from 1 June 1995. The service will make available television programme relay from the United States via Panamsat 2.

On 15 March, India's parliament approved a 31 per cent increase, to $330 million, in the 1995-1996 ISRO budget. The budget for the commercial space company Antrix Corporation was also increased 25 per cent, to $250 million. ISRO's budget covers the Polar Satellite Launch Vehicle, the cryogenic upper stage and other elements of the Geosynchronous Launch Vehicle, remote sensing satellites IRS-1C and IRS-1D, a new ocean data spacecraft Oceansat, the Insat communications and weather satellites Insat 2C, 2D, and 2E, a new launch pad, and miscellaneous space applications and space science programmes.

On 22 March, Japan's Diet approved a 1995 space budget of $2.56 billion, 5.1 per cent more than 1994's budget. The new budget doubled funding for the unpiloted shuttle Hope-Ex, to $106 million, and increased support for Earth observation by 54 per cent, to $531 million. ISAS was allocated the same level of funding as in 1994. It included funding for Lunar A, which will be launched in 1997 to investigate the Moon's internal structure, and Planet B, scheduled for launch in 1998 to study Mars' atmosphere.

United States President William Clinton and Ukrainian President Leonid Kuchma announced on 11 May an agreement for civil space cooperation. Specific elements included the flight of a Ukrainian cosmonaut aboard a United States Shuttle in October 1997 and negotiation of an agreement for commercial launch services by Ukrainian Zenit and Tsyklon rockets. Similar agreements are currently in force between the United States and Russia and China.

On 16 June, the French and Brazilian space agencies signed a cooperative agreement for work on satellite ground control and small satellite systems for Earth observation, beginning with development of a propulsion system for a small Brazilian Earth observation satellite.

The United States turned over the scientific instrument operation of the International Ultraviolet Explorer (IUE) spacecraft to a European-nation partnership on 1 October. The spacecraft has been operated by NASA's Goddard Space Flight Center (GSFC) since its launch in 1978. GSFC will still manage the IUE's "housekeeping" operations, but Spain's Villa Franca ground station will now collect the spacecraft's data for analysis by European and United States scientists.

From 23 October until 18 November the International Telecommunication Union hosted the World Radiocommunication Conference 1995 (WRC-95) in Geneva, Switzerland, at which substantial attention was given to issues relating to future low Earth orbit satellite radio frequency requirements and other radio regulatory issues involving space communications.

During 1995, the INTELSAT organization added its 135th member, Malta, on 20 January, and its 136th member, Botswana, on 14 April.

In January 1995, Afro-Asian Satellite Communications Ltd. of Bombay signed a US$ 700 million contract for two geostationary satellites on which they will base a new, satellite-linked hand-held telephone network serving Southern and Central Asia with plans to expand services later into East Asia and Africa. On 9 March Hughes Communications announced formation of Galaxy Latin America, a new partnership with Venezuelan Cisneros Group of Companies, Brazilian Televisao Abril, and Mexican MVS Multivision. Beginning in 1996, the new partnership will offer 144 television channels and 60 compact-disk quality music channels to individual households across Mexico, Central and South America and the Caribbean, using direct broadcast satellite technology. During June, Hong Kong company TVB International, a producer of Chinese language programming, leased a transponder from Panamsat, a US firm, to transmit television programming to Taiwan and countries in Northeast Asia.

In June, Daimler-Benz Aerospace announced that their Orbital Infrastructures Division signed an MOU with the Russian RKK Energia, of Kaliniingrad, and with Rockwell International of Seal Beach, CA, USA, for the 1997 launch of a free-flier camera that will permit inspection of the outer surface of the Mir Space Station. The German built camera will be launched aboard a Russian Progress supply vehicle. On 26 October, WorldSpace Inc., an American corporation, announced a contract with Alcatel Espace of France to build three satellites for US$ 600 million. The three satellites would make digital sound broadcasting available to 80 percent of the world's population. The contract includes the construction and launch of the satellites as well as the establishment of required ground stations on five continents. Some digital video will also be available from the satellites, but the mainstay of the programming would be high quality sound broadcasting.

In 1995, the International Institute of Space Law (IISL) continued both to develop the substantive law of outer space and to disseminate knowledge about space law. The major formal framework of the institute's work is its annual Colloquium at which papers on space law matters are presented and discussed. The 1995 Colloquium, the 38th, was held, as usual, in conjunction with the annual Congress of the International Astronautical Federation, which took place in Oslo, Norway. The Colloquium covered intellectual property, space debris and developments in international organizations dealing with space matters. The Institute also participated in the Congress on Public International Law, which was held at United Nations Headquarters in New York in March 1995 as part of the celebration of the fiftieth anniversary of the founding of the United Nations. A successful Round Table on Space Law, organized, chaired and contributed to by the Institute's President and other Directors and members, demonstrated the United Nations's accomplishments in this field of international law. Lead speakers focused on how the United Nations system had fostered the development of space law, particularly through the Committee on the Peaceful Uses of Outer Space (COPUOS) and the General Assembly, and also discussed the five international space treaties and the various Principles relevant to space which have been adopted by the General Assembly, and sought to discern where current and future discussions might lead.

In cooperation with the European Centre for Space Law (ECSL), the IISL organized a Symposium for the benefit of delegates to the 1995 session of the Legal Subcommittee of COPUOS, on "Technical and Policy Issues Related to the Use of the Space Environment."

Several other important conferences dealing with various aspects of space law were held in 1995. These included an International Symposium on "20 years of the ESA Convention," held in Munich in September, an International Colloquium on Air and Space Law, held at the University of Cologne in June, and an International Conference on "International Air Transport and Space Activities," held at Beijing in August. The ECSL's annual summer course on space law and policy was held this year in Aberdeen, Scotland, United Kingdom.

PART TWO: PROGRESS OF SPACE RESEARCH 1995

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

A. Satellites

The Russian Geostationary Operational Meteorological Satellite (GOMS) was launched on 1 November 1994, and installed in its nominal position 76 degrees east on 29 November. The first weather fax (WEFAX) transmission took place in June 1995.

The second European Remote Sensing satellite, ERS-2, was launched on 21 April 1995. ERS-1 will continue to operate in tandem with ERS-2 for the next year. For the first time, three satellite altimeters operated simultaneously: ERS-1 (from 1991), Topex/Poseidon (from 1992), and ERS-2 (from 1995). Other instruments include the second Along Track Scanning Radiometer (ATSR-2). This second model was based on the requirement to continue the database on sea surface temperature for climatology. However, three additional channels have been added, at 0.55, 0.66, and 0.87 micrometers; these channels will obtain high quality data over land by providing indicators of vegetation quality and quantity. ERS-2 also carries a Global Ozone Monitoring Experiment (GOME).

In August 1995, after three years in orbit, Topex/Poseidon, the United States-France altimeter mission, entered its extended mission phase. It continues to collect measurements of unprecedented accuracy on ocean topography, circulation, tides and mean sea level.

Meteosat-5 currently serves as EUMETSAT's operational satellite. Meteosat-6, launched in 1993, is expected to become operational when its radiometer lens anomaly is corrected through ground processing. The transition of Meteosat operations from ESA/ESOC to EUMETSAT was scheduled to take place by 1 December 1995.

Japan successfully launched its Geostationary Satellite-5 (GMS-5) in March 1995. It has infrared split window sensors, a water vapour channel and a visible channel sensor. GMS-4 was equipped with only a single IR and visible sensor.

The United States Geostationary Operational Environmental Satellite (GOES-9) was launched on 23 May 1995, and GOES-8 which was launched in April 1994, was declared fully operational in June 1995. The GOES-9, like GOES-8 is a three axis stabilized satellite and provides simultaneous imaging and atmospheric sounding capability. GOES-9 is expected to be declared fully operational near the end of 1995 when it reaches its nominal position of 135W. These satellites are capable of providing images every six minutes over selected 1,000 x 1,000 km areas and soundings on a full-time basis.

On 30 December 1994, the United States launched NOAA-14, the last in the current series of NOAA polar-orbiting satellites. In addition to the Advanced Very High Resolution Radiometer (AVHRR) imager and the TIROS Operational Vertical Sounder (TOVS), it includes the Solar Backscattered Ultraviolet (SBUV) instrument to provide measurements of ozone. Formal operations of NOAA-14 began on 10 April 1995, replacing NOAA-11, which was placed in a stand by mode.

Landsat-4 continues in a stand by maintenance mode, unchanged from 1994, and no imagery has been received since August 1993. Landsat-5's status also remains unchanged, with direct downlink of Thematic Mapper data to the United States ground station in Norman, Oklahoma, as well as to 15 international ground stations. Orbital maneuvers for Landsat-5 are scheduled for the fall of 1995 to return the local equatorial crossing time to its nominal position. Landsat- 7 development remains on schedule for a mid-1998 launch.

The launch of SPOT-3 in September 1993 resulted in a significant increase in the capacity and availability of the SPOT constellation which is now composed of three satellites in orbit. SPOT-2 is operated in direct acquisition mode only, in order to increase the coverage and capacity of SPOT-3, used as the prime operational spacecraft, with its full recording capacity available. SPOT-1 continues to provide high quality imagery and can be activated as a backup or as an additional service. SPOT-3 also carries DORIS and POAM-2, a UV/visible spectrometer procured by the Naval Research Laboratory and used in solar occultation mode to sound the polar stratosphere.

The Defense Meteorological Satellite Program (DMSP) F-13 was launched in March 1995. Earth observing instruments include the Special Sensor Microwave Imager (SSM/I) which is used for precipitation estimates, snow, sea ice, water vapor, and ocean surface wind speeds and the Special Sensor Microwave Temperature profiler (SSM/T).

B. Other Space Observations

A magnetometer was included in the complement of instruments on DMSP satellites F-12 and F-13 to monitor the near-Earth space environment. The fluxgate magnetometer measures the Earth's magnetic field and its variability in response to ionospheric currents. The other instruments (SSJ/4 and SSIES) monitor ionospheric plasma density, temperature, composition, motion, and scintillations and auroral particles. Data processing techniques to remove contributions from other currents and numerical models to compute atmospheric heating are being developed.

C. Future Satellites

The launch planning date of the first in the next series of polar-orbiting spacecraft, NOAA-K, is June 1996. The satellite's instrumentation will include the High Resolution Infrared Sounder (HIRS/3I), the Advanced Very High Resolution Radiometer (AVHRR/3), and the Advanced Microwave Sounding Units A and B (AMSU-A, AMSU-B).

Space environment monitoring systems on NOAA polar and GOES satellites continue to operate. The NOAA polar satellites monitor the *in situ* charged particle environment and GOES satellites also monitor local magnetic fields and solar x-ray flux. An upgraded space environment monitoring system is scheduled for launch on the first of the NOAA-K series of satellites.

The Canadian satellite Radarsat was scheduled for launch in October 1995. It employs a synthetic aperture radar (SAR) to provide all weather images of ocean, ice and land surfaces for use in environmental monitoring, ocean and sea ice studies and land use studies.

Meteosat-7, the first satellite to be launched under the Meteosat Transition Programme (MTP), is expected to complete integration and testing by mid-1996. It is expected to have an improved radiometer to avoid the anomalous behavior exhibited by Meteosat-6. It is planned for launch in 1997. The design of the Meteosat Second Generation (MSG) satellite is at an advanced stage of definition. The first such satellite, MSG-1, is scheduled for launch in mid-2000.

China is planning to launch two operational satellites in its FY-1 series in 1997-98 and 1999-2000. These satellites will have an improved multi-spectral radiometer compared to earlier experimental versions. It will have 10 channels; five in the short wavelengths (0.49-0.88 micrometers) three infrared channels (10.3-11.3, 11.5-12.5 and 8.4-8.7 micrometers) and two near infrared (1.58-1.64 and 3.6-3.9 micrometers.) All channels are capable of 1.1 km resolution. China is planning to launch a geostationary satellite, FY-2B in 1996. FY-2A failed before launch in 1994. It is a three channel (O.55-1.05, 10.5-11.5 and 6.3-7.6 micrometers) Visible and Infrared Spin Scan Radiometer (VISSR). Resolution will be 1.44 km for the visible and 5.7 km for the infrared channels.

The Indian Remote Sensing satellite (IRS-1C) is scheduled for launch in the last quarter of 1995. It will provide data from an array of three cameras for remote sensing of urban land use, cartography, geology and vegetation monitoring. The spatial resolution varies from 10 m for the panchromatic camera to 24 and 70 m in the visible and infrared for the Linear Imaging Self-scanning Sensor (LISS-III) and 189 m for the visible and near infrared Wide Field Sensor (WiFS). The IRS-P3 is next in the series of IRS-P satellites and is planned for launch near the end of 1995. It will have an X-ray astronomy payload and two remote sensing payloads; a Wide field sensor to be used primarily for vegetation dynamics studies and Modular Optoelectronic Scanner to be used for ocean related studies such as chlorophyll mapping, biomass monitoring coastal water discrimination, sediment transport and ocean dynamics. It will be launched into a near Sun-synchronous orbit at an altitude of 817 km with a 10:30 equatorial crossing time. An IRS-P4 mission is planned for the last quarter of 1996 with a Multi-frequency Dual-polarized Scanning Radiometer and an Ocean Colour Sensor (5 bands operating in the visible and IR). Its applications include physical and biological oceanography, agrometeorology and cartography, and meteorological studies.

Japan will launch the Advanced Earth Observing Satellite (ADEOS) in February 1996. The mission objectives of ADEOS include Earth, atmospheric and oceanographic remote sensing. ADEOS carries the Ocean Colour Temperature Sensor (OCTS) and the Advanced Visible and

Near Infrared Radiometer (AVNIR) as core instruments developed by the Japanese space agency, NASDA. ADEOS also carries six sensors from other agencies; the NASA Scatterometer (NSCAT) and the Total Ozone Monitoring Scanner (TOMS) provided by NASA, the Polarization and Directionality of Earth's Reflectance (POLDER) provided by CNES, the Interferometric Monitor for Greenhouse Gases (IMG) by Japan's Ministry of International Trade and Industries (MITI) and the Improved Limb Atmospheric Spectrometer (ILAS) and Retroreflector in Space (RIS), provided by the Environment Agency (EA).

Japan also plans to launch ADEOS-II, the successor to the ADEOS mission, in early 1999. ADEOS-II will take an active part in research of global climate changes, and will also be utilized for applications in meteorology, fisheries, etc. This will provide an understanding of the mechanisms of global environmental changes, including global warming. ADEOS-II will carry five core sensors: Advanced Microwave Scanning Radiometer (AMSR) and Global Imager (GLI) which are being developed by NASDA, Sea Winds provided by NASA, POLDER provided by CNES, and ILAS-II provided by EA.

The Tropical Rainfall Measurement Mission (TRMM) will be launched in August 1997. The payload will be provided jointly by NASA and NASDA. NASA will provide the spacecraft, TRMM Microwave Imager (TMI), Visible Infrared Scanner (VIRS), Lightning Imaging Sensor (LIS), and a radiation budget instrument (CERES). NASDA will provide Precipitation Radar (PR) and will launch TRMM on an H-II rocket.

NASA and NOAA have completed plans to modify the Advanced Composition Explorer satellite (ACE) to permit continuous broadcast of selected solar wind data. The satellite will be launched in 1997 and placed upstream of Earth near the L1 libration point.

SPOT-4 is under development and slated for launch in December 1997. Its primary high resolution imagery mission will benefit from an upgraded imager, the HRVIR. SPOT-4 will also carry DORIS, POAM-3 a follow-up to POAM-2, and the VEGETATION payload, a wide-field-of-view, medium-resolution push broom imager providing co-registered measurements in the same bands as HRVIR. VEGETATION is a cooperative programme of the EU, France, Belgium, Sweden and Italy.

The SPOT-5 programme, consisting of two identical spacecraft respectively scheduled for launch in 2002 and 2007, was approved by the French government in October 1994 and will ensure the continuity of the SPOT service until 2012. Just like SPOT 1, 2, 3 and 4, SPOT-5 is a cooperative effort between France, Sweden and Belgium. It will represent a major improvement over SPOT-4, with an along-track stereo capability, an increased resolution (10 m multispectral and 5 m panchromatic) and much more operational flexibility and capacity resulting from a three-imager configuration. SPOT-5 is equipped with high capacity (92 Gb) solid state recorders and has a five year design life time.

In a move to develop operational oceanography, CNES also plans to implement a series of small Topex/Poseidon follow-on satellites dedicated to altimetry, in order to ensure continuity of the Topex/Poseidon measurements from 1999 onwards, at the same level of performance. The Measurement of Pollution in The Troposphere (MOPITT) instrument will fly on the first Polar Orbiting Platform of the Earth Observing System (EOS), designated EOS AM-1, as part of the Mission to Planet Earth. MOPITT is a gas correlation spectrometer that senses vibration-rotation bands of carbon monoxide and methane molecules in the infrared part of the spectrum.

The Canadian Auroral Network for the Observation of Plasmas in the Upper Atmosphere and Space (CANAPUS) programme is Canada's contribution to the International Solar-Terrestrial Physics Programme (ISTP). It was accepted as an experiment in the NASA-Japanese Global Geoscience Study (GGS), which is a three-satellite component of ISTP. CANOPUS is set up to operate like one of the satellites and ranks on an equal footing with about 40 experiments on the spacecraft.

D. Composite Data Sets

Water vapour data from Meteosat-3 and Meteosat-5, processed at ESOC into upper tropospheric humidity and water vapour tracers, have been composited into monthly averages of upper tropospheric humidity and divergence for March, June, September, December of 1994 and March 1995. The products are provided as grid point values on a latitude-longitude grid at a resolution of five degrees.

Satellite measurements of aerosols from SAGE II and AVHRR were combined with vertical profiles of aerosol size distribution from selected stations to study climate forcing by aerosols. To assess the utility of SAR data for Great Lakes ice analysis, a data set consisting of ERS-1 SAR imagery, AVHRR imagery and *in situ* data were assembled.

Great Britain's National Environmental Research Council has assembled a variety of satellite, aircraft and *in situ* data sets for forest structure and biomass studies. Data sets have been assembled for Brazil, Sweden and England.

The Global Land 1 km AVHRR Data Set project has as one of its goals the collecting and archiving of daily 1 km AVHRR data from NOAA's afternoon polar satellites. It has thus far produced seven 10-day global composites of the normalized difference vegetation index for the interval of 1 April 1992 through 10 June 1992. These products are available from the United States Geological Survey's EROS Data Center and NOAA's National Climatic Data Center (NCDC).

As part of Canada's Sea Ice Monitoring and Modelling Site (SIMMS) field programme, physical properties and energy balance components are being measured over the sea-ice surface. These are then used as ground truth to compare with airborne and satellite (ERS-1) SAR measurements and with changes in large-scale atmospheric circulation.

E. Highlights of Scientific Results

1. Middle Atmosphere

A 15 year data set of ozone densities was generated by adding the data from the NOAA SBUV instrument on NOAA satellites from 1990-1994 to the NASA SBUV on Nimbus-7 from 1979-1990. Trends in global ozone densities were derived from this data set as a function of latitude and altitude.

Japan launches a meteorological rocket once a week from the Meteorological Rocket Observation Station (Ryori; 39.03N, 141.83E) to obtain data on atmospheric pressure, air temperature and wind direction and speed in the stratosphere and lower mesosphere (up to about 60 km). The Institute of Space and Astronautical Science (ISAS) has been launching one or two small rockets of the MT-series every summer and winter season for several years, to observe vertical distribution of ozone densities in mid-latitudes between a few and about 60 km in altitude. In September 1995, ISAS launched two rockets, MT-135-62 and -63 from Kagoshima Space Center (31.2N, 131.1E).

2. Lower Atmosphere

Satellite data are used in a number of weather and climate related studies. Examples of results are given below.

Studies of upper tropospheric water vapour obtained from the 6.3 micron water vapour band on NOAA satellites have shown that the large-scale circulation regulates the location and temporal variability of upper tropospheric water vapour. It was also shown that increases in greenhouse trapping are strongly correlated with increased middle and upper tropospheric humidity.

The study of upper tropospheric humidity and winds by Meteosat-4, and high-level clouds by NOAA polar orbiting satellites show high spatial coherence between data sets suggesting that large scale dynamics is the governing factor for the upper tropospheric humidity field and cloud formation processes. This has been confirmed by a similar analysis using GOES data.

Total column water vapour has been derived from Global Positioning System (GPS) satellites with an accuracy as good as or better than microwave radiometers or rain sondes.

Satellite observations of integrated water vapour, W, from the SMMR and SSMI instruments and satellite observations of sea surface temperature, SST, from AVHRR observations blended with *in situ* observations, show that the relationship between W and SST is much steeper than would be estimated directly from the Clausius-Clapeyron equation. This relationship is found on seasonal, inter-annual and decadal time scales. This result has important implications for general circulation models (GCMs) that have W-SST relations determined directly from the Clausius-Clapeyron equation.

An observation system experiment was performed to assess the impact of ERS-1 scatterometer data when wind speeds are used rather than full wind vectors. Results showed that use of wind speeds only gives a little less than half the impact of full wind vectors in forecasts of surface pressure for up to five days ahead.

The Japan Meteorological Agency assimilates precipitation data derived from GMS cloud data into the Japan Spectral Model through a diabatic initialization process in order to provide more favorable initial fields and increased forecast skill.

Improved radiation budget parameters are being produced from NOAA operational satellites. These include the downward longwave radiation at the surface, profiles of long-wave cooling rates and out-going long-wave radiation derived from HIRS sounding channels.

The second generation single channel aerosol optical thickness retrieval algorithm has been implemented operationally with the launch of NOAA-14 in December 1994. Its extensive validation using Sun-photometer data shows a systematic error of less than 5 per cent and the root-mean-square accuracy of about 0.04.

NOAA is developing a blended Precipitable Water (PW) product that uses SSM/I, GOES and model derived PW. This product will be used to determine antecedent "moisture" conditions prior to flash flood events. Last October, this blended PW product detected a strong northward surge of moisture from the Gulf of Mexico to Houston, Texas and points further north. Over 50 mm of PW were shown surging towards the Houston area. Houston received nearly 750 mm of rain during the subsequent three days.

NOAA/NESDIS began operational processing of GOES-8 soundings over the continental United States on an hourly basis. The Environmental Modeling Center of the National Weather Service used four layers of moisture, derived from these soundings, in their eight daily regional data assimilation system and determined that the information was useful to their model. Verification against radiosonde measurements show that the satellite data are more accurate than the 12-hour forecast.

The GOES-8 satellite measurements at five frequencies (the imager and infrared at 11 and 6.7 micrometers; the sounder at 7.2 and 7.5 micrometers) are being used experimentally to generate wind vectors in the vicinity of tropical storms. In some cases, especially with "exposed" centers, the entire vortex wind field is captured at low, middle and high levels.

Cloud estimates using the GOES-8 sounder continue to be used by NOAA's National Weather Service to supplement the cloud base observation of the Automated Surface Observing Stations. The CO_2 slicing algorithm is used to provide average effective cloud amount and pressure at each station. In addition, the product is prepared at full spatial resolution and depicted as a color-coded image hourly.

As part of an effort by NOAA and other United States agencies, satellite imagery is monitored for volcanic eruptions in order to provide volcanic hazard warnings of interest for aviation. Between January 1994 and August 1995, a total of 94 volcanos were monitored and 73 volcano hazard alert messages were issued and disseminated.

The satellite evapotranspiration component of the Canadian GEWEX study used georeferenced and calibrated NOAA-11 AVHRR scenes during the summer of 1994 over the Canadian GEWEX Mackenzie River basin to estimate evapotranspiration. Initial analysis indicated that simpler algorithms may overestimate evapotranspiration over the permafrost areas.

A preliminary study of column water vapour (CWV) retrievals from microwave brightness temperatures (DMSP SSM/I) has been carried out. Due to variable land surface emissivities at microwave frequencies, CWV retrievals are available only over the oceans. Nevertheless, they were found to be more beneficial than GOES (Humsat) retrievals, in spite of their lower temporal sampling rate. A reduction of 20 per cent in the CWV analysis error was obtained as a result of including the SSM/I CWV retrievals in the data assimilation.

3. Oceans

In July 1995, the United States Navy declassified and transferred to NOAA's National Ocean Service all satellite altimeter data collected by Geosat during its geodetic mission (1985-1986) allowing high resolution maps of global sea surface topography to be constructed. In a joint NOAA/NASA effort, the complete, 4.5 year Geosat data set (1985-89) will be upgraded and released on CD-ROM in 1996. These new data will include 10 cm orbits, a TOPEX-derived tide model, new corrections for timing and sea state biases, and a more accurate ionosphere correction.

NOAA's National Ocean Service investigated the cause of the relatively rapid global sea level rise observed by Topex/Poseidon from 1992-1995. The average rate of 5 mm per year is twice as large as the rate determined from tide gauges over the last century. Most of the anomalous increase occurred in the North Pacific and is consistent with inter-annual changes in sea surface temperature.

Twelve French teams are actively involved in the use of ERS and Topes/Poseidon satellite altimeter data. In the field of geophysics, 10 km resolution global maps of the marine geoid and related gravimetric and bathymetric fields have been constructed using merged data sets and are widely distributed. The glaciologists produced a 10 km topographic map of Antarctica, after complete reprocessing of one full 35 day cycle of ERS-1 data. Ice flow lines and surface slopes derived are distributed to modellers of polar caps dynamics. In oceanography, reprocessed, merged data sets are analysed to extract ocean signals, including accurate ocean and load tides, seasonal change of the steric height, mean sea level drift patterns, propagating Kelvin and Rossby waves in the tropics and subtropics, and their relation with western boundary currents. Assimilation into dynamical models is developed in the tropical oceans, the Mediterranean Sea and the North Atlantic. In the latter case, high-resolution quasi-geostrophic models are adjusted in near real time and prediction of mesoscale circulation in the Azores current area is made available routinely.

Three years of highly accurate DORIS measurements from SPOT and Topex/Poseidon have allowed the computation of the movements of beacons installed on all tectonic plates. The three-year displacements are in agreement with those estimated on geological time scales, except near plate boundaries.

Two new high-resolution altimeter data sets became available during 1995: the ERS-1 and the Geosat geodetic mission data. Together, these data have both the accuracy and density of coverage necessary to clearly resolve tectonic details in the marine gravity field on a global basis. NOAA's National Ocean Service constructed maps which, for the first time, provided views of the fine-scale tectonic features of much of the world's gravity field, as well as the sea floor.

The Japan Meteorological Agency uses near real-time Topex/Poseidon data for monitoring oceanic conditions in the Pacific. Topex/Poseidon data is analyzed on a ten-day cycle and sea surface topography maps are prepared within two weeks of its observations. The topography maps are used for monitoring sea surface currents in the western North Pacific and El Niño events in the tropical Pacific.

Russian scientists using data from the Almaz-1 satellite investigated the excitation of internal waves caused by current flows around the submarine cape, and the surface manifestation of internal waves in new regions were detected and investigated. The fields of wind driven waves and swells were also studied in various regions, and the two-dimensional spectra of the waves was computed and described. Atmospheric convective cells footprints on the sea surface and Langmuir circulations were revealed.

The British National Space Centre reported that an analysis of a ten year satellite wave height database has provided strong evidence of correlated inter-annual variability in the winter wave climates of the North Atlantic and North Pacific. In addition, the study concluded that cloud contamination of infrared data from ERS-1's Along-Track Scanning Radiometer (ATSR) leads to unrealistic differences between day and night mean sea surface temperatures (SSTs) and to poor comparisons with *in situ* SST data. A new cloud filtering process has been designed for post-processing of ATSR data to reduce cloud contamination and, hence, to improve the accuracy of SST data sets. These improvements are now being exploited in studies of ocean regions such as the Drake Passage and the northeast Atlantic.

Near real-time high-resolution satellite images from AVHRR on NOAA polar orbiting satellites are used by CoastWatch, a programme for monitoring the coastal environment of the United States. Products include sea surface temperature imagery and visible imagery (useful for ice analysis and for calculation of relative turbidity in estuaries). Images are mapped at about 1.2 km resolution for the coasts of the United States and at about 3.6 km for larger near-coastal ocean regions.

A computer-based sea-ice tracking system, which uses time-sequential images to extract ice motion from satellite data, has completed operational demonstrations on NOAA AVHRR, ERS-1 and aircraft SAR data and is now in an operationally-stable mode at the Ice Centre Environment Canada (ICEC).

4. Geology of Land Surfaces

The ERS-1 SAR has proven to be capable of providing calibrated, multi-temporal data sets. Rapidly changing geological events and the processes that underlay them such as volcanic eruptions and desert sedimentation can be monitored by SAR and increasingly quantitative use can be made of the backscatter properties of the surfaces. The potential of interferometric SAR techniques for measuring geomorphological and hazardous geological movements is now being realized.

India's Department of Space has used Landsat data to prepare wasteland maps of all States and Union territories in the country. It has also used IRS-1A/1B satellite data to prepare land use and land cover maps for agroclimatic zones.

5. Productivity of Land and Ocean

The British National Space Centre is developing applications of large-scale remote sensing of vegetation to address the effect of ecosystem interactions with the atmosphere on climate as well as monitoring climate change. Inputs to regional ecosystem models from remotely sensed data are being validated through field experiments on forest canopies as part of the MAC-Europe campaign carried out in 1991 in a Sitka Spruce plantation in central Wales and more recently on more complex forest ecosystems as part of the Boreal Ecosystems Atmosphere Study (BOREAS) in Canada.

India has used sea surface temperature from the AVHRR on NOAA satellites to locate thermal fronts and temperature changes as a means of locating favorable tuna fishing sites. India has also used the IRS-1A/1B satellite for estimating acreage of wheat, rice and sorghum and for estimating yields of those crops.

Algorithms for nighttime fire detection with visible-near infrared (VNIR) band data from the DMSP Operational Linescan System (OLS) were developed. This band has a capability to detect faint sources of VNIR emission present at the Earth's surface. Fire products have been developed for the United States and for southern Africa. DMSP-OLS fire observations were used as input into a model to estimate greenhouse gas emissions in Africa. Also improved resolution in GOES-8 3.9 micrometer imagery has allowed detection of nighttime forest fires on a scale of tens of acres.

The surface skin temperature from GOES infrared observations have been used in a surface energy budget model of the drought that took place in the United States midwest in 1988. Comparisons of spatial patterns of surface wetness from SSM/I and vegetation index from

AVHRR indicate possible utility of using those parameters in monitoring the fluxes of heat and moisture.

Satellite data have also been used by NASA scientists to document the impact of El Niño related droughts on vegetation in South America and Africa.

6. Pollution Monitoring of Atmosphere, Land and Ocean

Institutions in Britain have developed pilot programmes that utilize ERS-1 and ERS-2 satellite data as a surveillance tool for monitoring large areas of the ocean that are beyond the coverage and patrol of airborne sensor systems on a frequent basis. Information concerning the location, size and type of contaminants in the water is passed in near real-time to pollution monitoring agencies, who then can decide on a response strategy.

F. Contributions to International Programmes

A global monthly mean 2.5 x 2.5 degree grid field of precipitation is being prepared for the GEWEX Global Precipitation Climatology Project (GPCP). It consists of infrared and microwave estimates of precipitation blended with *in situ* gauge observations of precipitation. The initial data set will be from July 1987-June 1994. It is an international effort with contributions from the European space community, Germany, Japan and the United States.

A set of GOES data and products are being developed for the GEWEX Continental-Scale International Project (GCIP). The data include GOES-8 and GOES-9 imager radiances and statistics, insolation, photosynthetically active radiation (PAR), clear sky surface temperature, cloud height and amount. The software system began routine processing in November 1994.

The Committee on Earth Observation Satellites (CEOS) Working Group on Calibration/Validation (WGCV) has completed a "Proof-of-Concept" study of the feasibility of providing the user community with near real-time calibration updates for the visible and near-infrared channels of the AVHRR. The first set of updated calibration coefficients for the AVHRR on NOAA-14 spacecraft were implemented in NOAA's operations on 31 July 1995. The calibration updates can be accessed on the World-Wide Web. The techniques used to obtain calibration updates and results will be presented to the CEOS WGCV at the next WGCV meeting scheduled to be held in Toulouse, France, February 1996.

The BOREAS programme (see above) is a cooperative Canada/NASA field and analysis study aimed at improving the understanding of the interactions between the boreal forest biome and the atmosphere in order to clarify their roles in global change. The objectives of the programme are to improve understanding of the processes which govern the exchanges of energy, water, heat, carbon and trace gases between boreal ecosystems and the atmosphere, and to develop and validate remote sensing algorithms for transferring understanding of the above processes from local to regional scales. From August 1993 to September 1994, a continuous set of monitoring measurements (meteorology, hydrology, and satellite remote sensing) was gathered over a 1000 x 1000 km study area in the boreal forest of western Canada. Six field campaigns, each lasting approximately for three weeks, were carried out during the same period, involving 300 scientists and aircraft personnel and a total of 350 airborne missions.

The Asia-Pacific Space Geodynamics (APSG) project was recently initiated to investigate the geodynamical issues related to crustal motion by using space geodetic techniques such as satellite laser ranging, GPS, SAR as well as VLBI. Such scientific investigations will lead to a more basic understanding and will supply information for the prediction of earthquakes, volcanic eruptions and sea-level rise, in this vast region. Large parts of the region, where the tectonic character is complex and inadequately understood, are heavily populated and are experiencing rapid economic growth. The region is at extreme risk from tectonic, volcanic, seismic and other natural hazards. This project has been supported and adopted in resolutions of the Expert Symposium of the Ministerial Conference on Space Applications for Development in Asia and the Pacific (United Nations Economic and Social Commission for Asia and the Pacific), held in September 1994 at Beijing, China, and by the International Association of Geodesy which met in Boulder, Colorado in July 1995. Institutes and agencies in Australia, China, Japan, India, Korea, Pakistan, Russia, Germany and the United States are participating in the project. Details of the APSG project are being prepared as the organisational committees are being established.

G. Public Education and Awareness

China held an international satellite meteorology course in Nanjing from 5-16 September 1994. More than 30 students from 18 countries attended. Lectures covered topics such as the application of satellite data to tropical weather analysis and prediction, analysis and application of water vapour imagery and processing methods for polar and geostationary satellites.

H. Other Subjects that Merit Attention

NOAA's National Climate Data Center has completed several projects to make satellite data more accessible to users. Projects include making SBUV data available via the Internet and on CD-ROM, and placing Special Sensor Microwave/Imager (SSM/I) instrument (carried on the DMSP satellites) products on-line. Two years of SBUV Product Master File products have been placed on the On-Line Access Service and Information System, and six years of products have been place on CD-ROM. Eight years of SSM/I products (rain amounts, rain frequencies, liquid water, etc.) have also been placed on-line.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

A. The Moon and the Terrestrial Planets

1. Venus

A Discovery class "Venus Multi-Probe Mission" (VMPM) has NASA Phase-A funding to compete against two other proposals for flight funding in late 1995. If flown, VMPM will drop 16 small probes into the Venusian atmosphere, each containing experiments to measure wind and temperature profiles from the cloud base to the surface. The major scientific goals of the programme are to explain the super-rotation of the Venusian atmosphere and the relationship between atmospheric circulation and the surface "wind streaks".

2. The Moon

A new Discovery class mission named "Lunar Prospector" has been selected by NASA for a June 1997 launch. The spacecraft will carry six instruments. Global maps of the elemental composition of the Moon will be provided by a γ-ray spectrometer. A neutron spectrometer will search for water ice near the lunar poles. The discovery of water would be of enormous benefit to future exploration of the Moon and establishment of a permanently inhabited station there. An alpha-particle spectrometer will search for radioactive gases, specifically radon and its decay product polonium, as evidence of tectonic and volcanic activity. A Doppler gravity experiment, similar to that performed by Magellan at Venus, will provide a comprehensive gravity map. Weak magnetic fields will be mapped carefully by two instruments to study their possible origin as remnants of a global field, as the result of meteorite impacts, or from some other source.

The Japan's ISAS is planning a Lunar Penetrator Mission (LUNAR-A), which is to be launched in 1997. The scientific objective of the mission is to explore the lunar interior using seismometry and heat-flow measurements. In particular, the size and nature of the lunar core will be revealed by this study, which in turn will provide key constraints on the origin and evolution of the Moon. The mission consists of a 520 kg spacecraft in circular polar orbit around the Moon at an altitude of 300 km. Three penetrators will be deployed from the spacecraft onto the lunar surface, and will constitute a seismic and heat-flow measurement network of a larger span than the Apollo ALSEP network. Two of the three penetrators are planned to be deployed at the near side of the lunar surface and the other is on the far side. The penetrators are expected to penetrate 1-3 m into the lunar regolith.

3. Mars

NASA will launch two spacecraft to Mars in late 1996, Pathfinder and Mars Global Surveyor. The Russian Federation will launch Mars-96, which consists of an orbiter, two small landers, and two penetrators. Pathfinder is a Discovery class mission which carries a small rover, formally called the Micro-rover Flight Experiment (MFEX) but familiarly called "Rocky" for its rocker-bogie suspension.

Pathfinder will make a direct entry into the Martian atmosphere in July 1997, using parachutes, solid rockets, and air bags to land safely. Pathfinder will take panoramic pictures during its descent and collect some atmospheric data. The camera will guide and log Rocky's travels after landing. Rocky will carry an alpha-proton-x-ray spectrometer for elemental analysis of the solids over which it travels as well as a camera for close examination of the Martian surface. Rocky will move from a few to some tens of meters distance from the mother spacecraft, limited mainly by the need for a line-of-sight for communications to Pathfinder, which transmits all data back to the Earth. Mars Global Surveyor will arrive at Mars in September 1997, going into an elliptical orbit which will be circularized by thruster firings and aero-braking. It will carry a camera, a mid-IR thermal emission spectrometer for surface and atmospheric studies, and laser altimeter and radio science experiments to determine the physical figure and gravitational field of Mars to greatly improved accuracy for future missions. It is intended that such orbiters be launched every 26 months as a part of the Mars Environmental Survey (MESUR) programme and to serve as data relay systems for spacecraft beginning with the penetrators and landers of Mars-96.

The Russian Mars-96 orbiter will carry cameras, UV, visible, and IR spectrometers, and an IR radiometer to study surface mineralogy, a long wave radar to search for sub-surface water, neutron and γ spectrometers to study elemental distribution on the surface, and a neutral mass spectrometer to measure the elemental composition of the fringes of Mars' upper atmosphere. The landers will make atmospheric measurements during descent and surface chemistry, seismicity, magnetic, and atmospheric meteorological measurements after landing. The penetrators will measure elemental composition and water content of the ground in which they land and will also image the area around the impact sites.

The Planet-B programme of Japan's ISAS was started in April 1992. The programme aims to clarify the structure and dynamics of the Martian upper atmosphere and its interaction with the solar wind. ISAS will send an orbiter to Mars in 1998. It will arrive in late 1999 and take a low periapsis at 130 km altitude in order to survey the most important altitude range of the Martian ionosphere. It will take a large apoapsis distance of 15 Mars radii to study the night side of the Martian magnetosphere where escaping energetic ionospheric ions, causing the mass loss of the Martian atmosphere, are expected.

B. The Outer Planets

1. Jupiter

On 12 July 1995, the Galileo spacecraft successfully released its probe, which is now a separate spacecraft heading towards entry into Jupiter's atmosphere on 7 December 1995. On 20 July, Galileo spun down from the temporary 10.5 rotations per minute (rpm) necessary to give the probe stability to 3 rpm for an attitude check in the preparation for re-orienting itself for the deflection burn necessary to keep it from following the probe into the Jovian atmosphere.

Following a brief test burn, the German built main rocket engine fired in earnest for the first time on 27 July to place Galileo behind and to one side of the probe, where it will act as a relay station for the probe transmissions in December. Galileo will then make a very long burn to put itself into Jupiter orbit for the extended study of Jupiter and its Galilean satellites.

2. Saturn

The Cassini-Huygens mission to Saturn is on schedule for an October 1997 launch. The spacecraft will have a launch mass of 5,655 kg, including 3,132 kg of propellant, the 373 kg Huygens probe, and 366 kg of scientific experiments. It is scheduled for insertion into Saturn's orbit in early July of 2004 after switching past Venus twice and Earth and Jupiter each once in gravity assist maneuvers. The current plan is to release the Huygens probe in early November, late in the first orbit of Cassini around Saturn, for its mission to enter and study the atmosphere and surface of Saturn's largest satellite, Titan. Cassini will deflect and serve as a relay station for Huygens. During its nominal four year Saturn tour, Cassini will make 40-80 orbits of Saturn, depending upon the details of the tour selected. Cassini has 12 instruments and Huygens six, many of them with multiple devices and modes of operation, making this one of the most complex and potentially rewarding scientific missions ever flown.

3. Pluto / Charon

Pluto remains the only planet not yet visited by spacecraft. NASA continues to study a possible dual Pluto Fast-Flyby mission, and it remains in their strategic plan for launch in 2002 or 2003. The spacecraft would arrive about six months apart 10 years later, before Pluto's atmosphere begins freezing out on the surface for another 200 years in about 2015. Each spacecraft would include a camera and two spectrometers in one small integrated 7 kg package.

C. Small Bodies in the Solar System

1. Comets

The ESA cornerstone mission to a comet is the Rosetta comet rendezvous and landing mission, scheduled for launch to P/Wirtanen in 2003 with arrival in 2011. The mission consists of an orbiter and two landers. The landers will approach the surface in 2012 at about 3 AU solar distance before the onset of strong cometary activity. The landers are RoLand (Germany) and Champollion (France/United States). The baseline mission includes two asteroid fly-bys, 3840 Mimistrobell in 2006 and 2530 Shipka in 2008. Rosetta will orbit P/Wirtanen for about two years. Experiment selections for the orbiter and the landers are in progress.

Stardust, a Discovery class mission currently in phase-A study and competing for flight funding with VMPM (see above) and a solar wind study (Suess-Urey), is a mission to comet P/Wild 2 which will capture interstellar dust. If flown, Stardust will capture intact cometary particles in aerogel, during a fly-through of P/Wild 2 on about 1 January 2004 at a distance of about 100 km. The particles will then be returned to Earth for analysis in 2006. It also will image the P/Wild 2 nucleus at a resolution of about 100 km and count and analyze dust grains *in situ*. The analysis will be conducted with a German supplied ionization impact time-of-flight mass spectrometer, similar to those flown successfully with the Giotto and Vega spacecraft to study the dust environment of comet P/Halley.

2. Asteroids

The Near Earth Asteorid Rendezvous (NEAR) mission will provide the first spacecraft to orbit an asteroid, 433 Eros. This first Discovery class mission to be flown will be launched in February 1996, will fly past asteroid 253 Mathilde in June 1997 at a velocity of 9.9 km s^{-1}, swing past the Earth in January 1998, and finally rendezvous with and enter orbit around 433 Eros in January 1999. NEAR will then study 433 Eros for almost one year with a multispectral imager, a near infrared spectrometer, an X-ray and gamma-ray spectrometer, a laser rangefinder, a magnetometer, and a radio science experiment. This suite of instruments should give detailed elemental composition at 4 km resolution, mineralogical composition at 300 m resolution, and physical resolution at about 10 m, as well as maps of the magnetic field and density of 433 Eros.

Rosettta, (see above) will fly by two asteroids, 3840 Mimistrobell in September 2006 at a velocity of 6.1 km s^{-1} and 2530 Shipka in October 2008 at a velocity of 13.2 km s^{-1}. Each will be studied with all applicable selected orbiter instruments, including imaging instruments.

3. Dust

If flown, the Stardust mission (see above) will orient about 0.1 m^2 of aerogel in a position to capture interstellar dust on three occasions for periods of several months during its flight to and from comet P/Wild 2. At these times, the dust discovered by Ulysses will be overtaking the spacecraft at a relative velocity of only 20 km s^{-1}, making its intact capture possible. The dust would be received on Earth in 2006.

III. SPACE STUDIES OF THE UPPER ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

A. The Earth's Middle Atmosphere and Lower Ionosphere

The middle atmosphere and lower ionosphere, the region between 20 and 110 km in altitude, continues to be the focus of extremely active research, involving all the major nations of the world who engage in solar terrestrial physics research programmes. Understanding of this region is critical for a comprehensive appreciation of the interactions between the Sun and Earth, and essential for studies of climate change and of anthropogenic influences upon composition and dynamics. Much of the research is coordinated with, or consistent with, the 1990-1997 Solar Terrestrial Energy Programme (STEP), and with the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) programme being conducted in the United States. Both of these efforts contain major working groups focusing upon this area; and both of these communities held major planning meetings during 1995 (see below). The Upper Atmosphere Research Satellite (UARS) also continued to provide unique data on constituents, temperatures and winds during 1994-1995, providing opportunities for collaborations with many ground-based observing systems.

Considerable efforts were made on the analysis and interpretation of data from campaigns held during 1993-1994 and from UARS. For example, ANLC-/ALOHA-93 provided opportunities to study the dynamics and structure of the mesopause regions at mid to high latitudes (Canada) and also at the equator (Hawaii to Tahiti). Instruments included the CEDAR-lidar on the NCAR Electra and ground-based optical and radar systems. ANLC93 involved 12 universities and ALOHA-93 involved 16 universities and laboratories. Following the preparation of short papers (published in Geophysical Research Letters), a major workshop was held on the Island of Lana'i (Hawaii) in May 1995 to plan the major research studies and papers. Topics to be covered include Sporadic-Sodium layers, noctilucent cloud (NLC) and polar mesospheric clouds (PMC) observations and the related dynamics and temperature structures, gravity waves (parameterization, spectra, heat and momentum fluxes), tides, temperature responses to dynamics, and effects of tropospheric storms. There have been many published studies on dynamics this year involving UARS (WINDII and HRDI instruments), in collaboration with ground-based systems. UARS is now confirming and expanding the view of wave and wind interactions developed from radars during 1980-1992. In particular, tidal global climatologies and model comparisons have been most impressive. A workshop was held in Paris in November 1994 to focus on the various methods of wind measurements available, and their advantages and disadvantages. The comparisons between the major systems (UARS, radars, optical, rocket) are largely satisfactory, but some biases are evident (radars often provide smaller magnitudes). Work continues on this topic, and collaborations which benefit from the combination of global/temporally-intensive soundings.

There have been several successful missions or campaigns conducted over the past year. The NASA Shuttle experiments CRISTA/MAHRSI (Germany) had a successful flight in November 1994, with spatially well-distributed accompanying aircraft, balloon, rocket and optical system measurements. These will investigate the aeronomical/composition and dynamical structures of the Middle Atmosphere and Lower Ionosphere. A planning meeting dealing with data analysis/applications was held during the July 1995 IAGA meeting. Other global campaigns included those of the Mesosphere Lower Coupling Study (MLTCS of STEP), involving about 30 radars (MF, Meteor, MST, Incoherent Scatter), and focusing on mean winds, tides, planetary waves and gravity waves and their mutual interactions: December 1994-February 1995, July-August 1995 for PW studies, and 10-16 August 1994, and 23-27 October 1995, with the IS Radars. A workshop to intensively study an earlier 10-d interval (January 1993) was held at Boulder in January 1995 (CEDAR/MLTCS).

Perhaps the most significant Middle Atmosphere satellite presently being developed is the Swedish Odin, which is being developed in cooperation with Canada, Finland and France. The satellite, scheduled for launch in 1997, will provide global data on aeronomy/minor constituents and structures, allowing for study of the ozone "holes", PMCs and stratospheric warming influences. Collaborations with ground-based systems capable of dynamical measurements are now being planned.

As first reported in 1994, the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) has been established near Andenes (69N) on Andoya, Norway. The observatory has investigated the physics, chemistry and meteorology of the Lower and Middle Atmospheric regions during 1994-1995. The instruments utilized have included a Rayleigh/Mie/Raman lidar (10-80 km altitude; now with wind measuring capability), an Ozone lidar, the revised/upgraded SOUSY VHF/MST radar and an IR scanning radiometer. Other systems near Tromso (EISCAT, MF radar) were also used. An MF wind radar is now being installed as part of the ALOMAR system. The polar mesospheric summer echo (PMSE) event, as studied during the ECHO-94 campaign of 1994, was very intense, and is currently being explored in unprecedented detail, using rocket-data as well as ALOMAR systems. The analysis of data is on-going and several events of co-located layers of PMSE and NLCs have been observed. The temporal variability was found to be related to the tidally modulated wind field measured by the Tromso MF radar.

An international workshop on NLC was held in association with the International Union of Geodesy and Geophysics (IUGG) General Assembly in 1995. Participants reviewed the status of the field and presented new results pertaining to the high altitude clouds also known as polar mesospheric clouds (PMC). Intense debate continues as to the relationship between the occurrence of NLCs and possible anthropogenic forces and the mechanisms responsible for their formation. The findings of the workshop will be published in a special issue of the Journal of Geophysical Research (Atmospheres section) in 1996.

The major 1995 meeting on solar terrestrial physics meeting was the July IUGG General Assembly in Boulder, Colorado, United States. There were also several major International Association of Geomagnetism and Aeronomy and International Association of Meteorology and Atmospheric Sciences (IAGA/IAMAS) symposia including: Middle atmosphere dynamics, radiation and transport (including solar terrestrial interactions, and the polar mesosphere); Equatorial atmosphere and ionosphere interactions; Comparisons of middle atmosphere models; and Upper atmosphere (80-300 km) structure, dynamics and electrodynamics; and gravity wave sources and parameterization. Well balanced studies featuring observations, modelling and theory are ensuring that significant progress on the objectives of STEP and CEDAR are being made. There was also a three-day SCOSTEP/STEP meeting during the IUGG interval. While STEP is flourishing, plans for post-STEP activities are also well advanced. S-RAMP, the Results, Applications, Modelling Phase (1998-2002), and PSMOS (Planetary Scale Mesopause Observing System) will ensure that programmes are in place to optimize the efforts of STP researchers well into the 21st century.

The Wind Imaging Interferometer (WINDII) on NASA's UARS has now made extensive analyses of upper atmosphere winds from the oxygen I 557.7 nm airglow emission, for both day and night. In addition, observations of the emission rate provide information on the atomic oxygen distribution, which is clearly affected by both tides and planetary waves. It was discovered that large vertical perturbations in the atomic oxygen distribution occur at the equator when the diurnal tide penetrates to this altitude. The daytime green line emission rate correlates well with the solar flux, and shows very large enhancements during solar flares. WINDII has also mapped the distribution of PMCs in the northern and southern hemispheres.

B. The Earth's Upper Atmosphere and Ionosphere

The Multi-instrumented Studies of Equatorial Thermospheric Aeronomy (MISETA) effort is one of several new CEDAR initiatives and is devoted to the study of the causal mechanisms responsible for the onset of ionospheric irregularities at equatorial latitudes. The first MISETA campaign in 1995 featured a combination of digisondes, Fabry-Perot interferometers, all-sky cameras, radars and satellites configured to address the poorly understood phenomena associated with ionospheric structuring. Results from the effort are being analyzed and will be published shortly. Plans for a second intensive campaign to be conducted during 1996 are underway.

Experimental work to describe and understand the morphology and occurrence of "Sprites" has intensified. Sprite is the name given to the short-lived, large-scale stratospheric/mesospheric optical emission associated with tropospheric lightning discharges. It is expected that the first detailed spectrum of a Sprite will be published soon and further work in 1996 will address more quantitatively the issues of occurrence, spectral nature of the emission, physical size of the emission region, and associated energetics.

An inter-agency working group has been established within the United States to prepare for the development of a National Space Weather Service (NSWS) devoted to the improvement of predictive capabilities for the near-Earth space environment. Summer workshops associated with the 1995 CEDAR and GEM annual meetings were also devoted to this topic.

Additional collaborative studies are being facilitated by new computation tools for interactions over the Internet. In one such study, extensive international interest is being focused on a particular space-weather event that occurred in November 1993. This event was characterized by a major magnetic storm (-105 nT Dst) for which comprehensive experimental coverage from an array of satellites and ground-based instruments is available.

Interested scientists will find details of the on-going effort at the World Wide Web site: http://igpp.ucla.edu/gern/event_nov93.html. The Upper Atmosphere Research Collaboratory (UARC) programme is a test bed for the development of Internet-based collaboration tools using the space science community as a test bed. The present UARC effort is focused on the use of the Sondrestrom Observatory and participants include scientists from Canada, Denmark and the United States. The UARC development has led to a "common windowing" computational environment that allows for real-time geophysical data to be displayed and discussed over an international network, eliminating some of the travel requirements associated with field campaigns.

The Polar Cap Initiative of the United States National Science Foundation has entered its initial phase, the establishment of the Early Polar Cap Observatory (EPCO) at Resolute Bay, Northwest Territories, Canada. The EPCO is now operational with a combination of optical and

HF-radio instruments from the United States and Canada. Plans to expand this facility include the development of a new phased array incoherent scatter radar system which is planned for the latter part of the decade. This facility will be used to investigate the mesosphere, thermosphere and ionosphere within the central portion of the geomagnetic polar cap.

The new EISCAT Svalbard radar system (500 MHz) is under construction near Longyearbyen in the Svalbard archipelago. It will be in operation in late 1995 with one antenna. Japan has decided to join the EISCAT community by providing a second antenna at Svalbard. The facility will study the polar ionosphere and magnetosphere in the cusp region. The Norwegian Space Centre has announced the possibility for launches of scientific sounding rockets from Ny Elesund at Svalbard. Such rockets can be launched along the magnetic field lines and into the polar cap.

Considerable progress was made in 1994-1995 using UARS Dynamics data (from the WINDII and HRDI wind measuring systems) to study the spatial variability and structure of wind systems, and compare and contrast these with the detailed temporal view available from radar systems operating in MLTCS. Recent UARS work includes the identification of five day waves in the lower thermosphere, more detailed specification of the diurnal tides, and multiple correlative studies using ground-based data sets. There will be many results of this work published in 1996.

The observations by the Shuttle-borne GLO experiment have provided detailed spectral observations of airglow below the orbital track. These high-spectral resolution measurements are being compared with a large set of correlative ground-based observations and the results will also be published during 1996.

The Thermosphere/Ionosphere and Mesosphere Energetics and Dynamics (TIMED) mission continues to be developed. The four instruments under development for this mission include a UV imaging spectrometer, a Fabry-Perot interferometer, an IR limb scanning instrument and a solar EUV spectrophotometer. Its launch is still planned for 1998.

Work on the International Reference Ionosphere (IRI), the standard ionospheric model, was reviewed and discussed during the 1995 IRI Workshop at the National Physical Laboratory in New Delhi, India. Focusing on the low latitude ionosphere, the workshop provided an opportunity to discuss much needed improvements of ionospheric models in the equator anomaly region. This is a critical region in many ways because it is the area on the globe where the largest values are found in the total electron content (TEC). The ionospheric refraction effect on traversing electromagnetic waves (e.g. radio waves, remote sensing signals) is directly proportional to TEC. Several new initiatives were started at the meeting including attempts to add to IRI a global description of the ionospheric ion drift and of the distribution and occurrence of Spread-F.

Since the summer of 1994, a quarterly IRI Newsletter is published by K.-I. Oyama at ISAS in Japan. The newsletter provides a forum for the exchange of ideas and experience with

IRI usage and improvements.

With only a few new satellite missions in ionospheric/thermospheric science in recent years, some efforts are now being directed towards making some of the unique older space physics data sets directly accessible on the Internet. NASA's National Space Science Data Center (NSSDC) is putting much of its more recent space physics data holding onto an Automated Retrieval Mail System (ARMS) for direct user retrieval over the Internet. Satellite missions already represented on ARMS include IMP-8, DE-1, DE-2, Hawkeye, and ISEE. San Marco, Alouette-2, ISIS-1, and ISIS-2 data sets are in preparation. Another interesting effort concerning older space data is now underway at the Goddard Space Flight Center. This activity involves the conversion of analogue topside ionograms from Alouette-2, ISIS-1, and ISIS-2 into digital form. The old tapes are in danger of being lost permanently due to storage limitations at their current storage facility in Canada. Only a small percentage of these data is currently available either as processed ionogram data on microfilm or as reduced electron density profiles on magnetic tapes.

C. Planetary Atmospheres and Aeronomy

The Interball Tail Probe was successfully launched from the Russian Federation on 3 August 1995. The second part of this mission, the Auroral Probe, is scheduled to be launched in early 1996. Both probes carry payloads for the studies of plasma, magnetic and electric fields and wave phenomena in the magnetosphere of the Earth.

The spectacular fall of the Shoemaker-Levy 9 comet fragments on Jupiter in July 1994, was observed by hundreds of telescopes. The analysis of gigabytes of data obtained provides a unique insight into the composition of the cometary nucleus, the Jovian atmosphere below the visible cloud tops, and in the physical and chemical processes which occur during the impact of celestial bodies at 60 km/s velocity.

The proposals for scientific experiments to be flown on ESA's Rosetta cometary mission are currently being evaluated.

In April 1995, the Hubble Space Telescope (HST) celebrated its fifth year in orbit. Since its launch in 1990, HST has captured the images of objects of the solar system at a resolution comparable to that attained in spacecraft fly-bys. In 1994 and 1995 HST observed the collision of the Shoemaker-Levy 9 comet with Jupiter, discovered a new dark spot in the northern hemisphere of the cloudy atmosphere of Neptune, and mapped the ancient surface of asteroid Vesta.

The Galileo spacecraft is on its way to Jupiter where it was scheduled to arrive in early December 1995. It will deploy an atmospheric entry probe and then go in orbit around Jupiter. This mission will provide extensive measurements of the atmosphere and magnetosphere of Jupiter.

The Russian Federation Mars-96 (former Mars-94) spacecraft is currently undergoing tests.

The launch was scheduled for November 1996. The mission consists of an orbiter and four small landers, two of which will perform soft landings and two which will penetrate the surface. The instruments on the orbiter will be used to study the Martian atmosphere and plasma environment, and the Martian surface. All of the landers carry sensors for meteorological monitoring in addition to the instruments for surface layer studies. International cooperation, involving over 20 countries, is a key feature of this mission. Mars-96 will be the last Russian planetary mission of the century. A Joint United States-Russian Federation Science Steering Committee is discussing possible joint activities under the Mars Together Programme, including Russian participation in the scientific payload of the United States 1998 Mars Surveyor mission, and development of a joint United States-Russian Federation mission to Mars in 2001.

A possible joint mission to Pluto after 2001 is also under consideration.

The Mars-Pathfinder spacecraft is being readied for a 1996 launch. It is nominally an engineering demonstration test of the landing system, but it will also carry the following instruments: an imager, an atmospheric structure cluster and an alpha-proton-X-ray spectrometer, which will be deployed by a mini-rover. The other Discovery mission, NEAR (Near Earth Asteroid Rendezvous), will also be launched in 1996 and make measurements on bulk properties (e.g. size, shape, volume, spin state), surface properties (e.g. elemental and mineral composition, geology, structure) and internal properties (magnetic field, mass distribution) of asteroids. The Mars Global Surveyor spacecraft is also on schedule for a 1996 launch. It will carry the same instrument complement as the ill-fated Mars Observer, except for the pressure modulated infrared radiometer and the g-ray spectrometer.

A new mission to Mars, Mars Global Surveyor-98, has been approved to follow the 1996 mission and Mars Pathfinder to the red planet. The new project will carry the Pressure Modulator Infrared Radiometer (PMIRR) into polar orbit, for studies of the Martian atmosphere, including temperature structure, water vapour, and dust distributions. The data should characterize the present-day Martian general circulation and climate over a complete seasonal cycle, approximately two Earth years.

In Japan, the ISAS Planet-B mission to Mars was initiated in 1992 and is on schedule for a 1998 launch. The main scientific aim of this programme is to study the Martian upper atmosphere/ionosphere and its interaction with the solar wind. It has a very extensive and ambitious scientific payload and some of the instruments are being developed in collaboration with Canada, Germany, Sweden and the United States.

The Cassini mission is in the hardware development and construction phase and will be launched by NASA in October 1997. It will carry the Huygens Probe, built by ESA, which will make measurements of the atmosphere of Titan. The Cassini Orbiter will make comprehensive measurements of the atmospheres and plasma environment of Saturn and Titan.

NASA recently selected the Lunar Prospector as its third Discovery mission and it will be launched in 1997. It will carry out low altitude mapping of the moon as well as make measurements of surface composition, magnetic fields, gravity fields and gas release events. Also selected for further study were the following three other potential missions: Stardust (cometary/interstellar dust sample return), Suess-Urey (solar wind sample return) and the Venus Multiprobe Mission (release of 16 probes to study the super-rotation of the Venus atmosphere).

The joint ESA-NASA Rosetta mission is now in the instrument selection phase. The plans call for the Rosetta spacecraft to rendezvous with a comet and also to deploy two surface landers. The successful completion of this mission would lead to a major advance in the understanding of comets.

A vigorous programme of theoretical studies of planetary atmospheres and plasma environments is continuing. Some of the activities are associated with the interpretation of past data sets as well as predictive studies associated with future missions.

D. Trace Species in the Earth's Atmosphere

The Prediction and Retrospective Ionospheric Modelling over Europe (PRIME) project has been finalized, providing a new computerized product to be implemented in ionospheric research and applications. A new COST-251 Project has started as a continuation of PRIME under the title Improved quality of services in Ionospheric Telecommunication Systems planning and operating (IITS). Among other subjects, the goals of IITS include improvements and validation of the ionospheric models for Earth-space systems, short-term and long-term ionosphere variability and forecasting. Another promising issue is the Ionospheric Database on CD-ROM created at WDC-A for STP, Boulder, Colorado, United States, jointly with other World Data Centres (WDC-B for STP, Moscow, Russian Federation; WDC-C1 for STP, Oxford, United Kingdom; WDC-C2 for Ionosphere, Tokyo, Japan; European Regional Databank, CNET, Lannion, France). A CD-ROM with ionospheric and thermospheric data from the Atmosphere Explorer Satellites was issued by NASA's National Space Science Data Center (NSSDC).

IV. SPACE PLASMAS IN THE SOLAR SYSTEM

The most tenuous regions of the solar system are in the plasma state, from the outer corona of the Sun and the solar wind to the magnetosphere and ionized atmosphere of each of the planets, which also includes the extended plasma environments of comets. Our knowledge of the physics of plasmas in space comes mainly from *in situ* and remote sensing measurements made by space probes, but important information has also come from balloons, rocket probes, and ground based facilities.

The Ulysses spacecraft, built by ESA and launched by NASA in 1990, completed its first passage over the solar poles in September 1995. The mission is the first ever to explore solar latitudes above 35 degrees and has made a number of important discoveries. With regard to the solar wind flow, a transition from the familiar gusty slow wind at low latitudes to a relatively smooth and constant fast wind at around 750 km/s at high latitudes has been firmly established.

The composition of the wind differs markedly from one flow regime to the other and the transition is sharp. The dipolar nature of the magnetic field known to exist at the surface of the sun has not been found at high altitudes (around 2 AU over the poles). Cosmic ray intensity over the solar poles is not significantly greater than the intensity at low latitudes. This finding confounds beliefs held for many years. In a intriguing development, Ulysses' energetic ion measurements have been interpreted to exhibit fluctuations related to solar gravity modes, which carry information on the deepest regions of the Sun's interior. In October 1995, Ulysses embarked on a second six year orbit of the sun which will make possible an examination of the solar poles at a time of maximum solar activity when the solar atmosphere will differ greatly from its quiet configuration in 1994 and 1995.

The ICE spacecraft started life as International Sun Earth Explorer (ISEE3) in 1978. For several years now it has been used to provide an in-ecliptic baseline for comparison with Ulysses measurements. Coverage has been very limited and present plans are to cease operation early in 1996.

The Pioneer-10 and -11 and the Voyager-1 and -2 spacecraft were launched by NASA in the 1970s, and after passing by the planets are all at large distances from the Sun. These spacecraft are still being used to study the solar wind, the interplanetary magnetic field and cosmic radiation. An interesting detection has been made of electromagnetic radiation believed to be returning from the heliospheric boundary following its stimulation by a strong disturbance in the solar wind. The approximate distances of these spacecraft from the Sun in July 1995 were: Pioneer-10, 63 AU; Pioneer-11, 43 AU; Voyager-1, 59 AU and Voyager-2, 46 AU. Pioneer-10 should be able to continue operation for a few years and the Voyagers for perhaps a further 20 years. However, Pioneer-11 has just enough power remaining to occasionally operate one instrument and it seems that it may be near the end of its useful operation.

The NASA SAMPEX spacecraft, launched in 1992 into a near-Earth polar orbit, has facilitated the study of the arrival and storage of anomalous cosmic rays in the Earth's radiation belts. In addition, SAMPEX's energetic electron measurements have shed light on the cause of the malfunction of a number of commercial satellites. It has also provided ecliptic plane baseline information for Ulysses' polar passage.

NASA's Galileo Jupiter orbiter is on its way to rendezvous with the planet. In July 1995, it deployed the atmospheric probe, and directed itself into a path that leads to the beginning of the orbital mission. In December, the orbiter and probe will reach Jupiter separately. The orbiter will fly close to Io and make its closest approach to Jupiter in order to receive and record the probe signals as it descends through Jupiter's atmosphere. The orbiter will then brake with its main engine and go into orbit around Jupiter to study its magnetosphere.

The Swedish-German satellite Freja was operated regularly until July 1995 and has provided data on the auroral regions with unprecedented time resolution. Flying at altitudes of up to 1,750 km, Freja is primarily investigating the lower reaches of the auroral acceleration region where the interaction with the ionosphere manifests itself most clearly, although one of the surprising discoveries was the observation of very large electric fields at sub-auroral latitudes.

The launch of the FAST satellite within NASA's small explorer programme, originally scheduled for July 1994, was again postponed in 1995 because of further delays in development of the launcher. FAST will study the auroral acceleration region at higher altitudes and with even greater time resolution than Freja.

The large multi-spacecraft programme, referred to as the Inter-Agency Solar-Terrestrial Physics Programme (IASTP), to investigate plasma processes in the near-Earth space entered its main phase with the launches of the first of the NASA contributions, Wind, in November 1994 and the first of the Russian Space Agency contributions, Interball-Tail, in August 1995.

Wind's main goal is to study phenomena in the solar wind and to monitor conditions upstream of the magnetospheric system. For this purpose, Wind will eventually be placed in a halo orbit around the L1 libration point between the Earth and the Sun. But during its first year of operation it used periodic encounters with the Moon to maintain a variable size orbit around the Earth which allowed for studies of the Earth's magnetopause, bow shock and foreshock regions, in addition to those of the solar wind.

The Interball programme is led by the Russian Space Agency, but also involves Austria, Bulgaria, Canada, the Czech Republic, ESA, Finland, France, Germany, Hungary, Italy, Kirgizia, Poland, Romania, Slovakia, Sweden, United Kingdom and Ukraine. Interball-Tail is actually a satellite-subsatellite pair in an eccentric orbit with 63 degrees inclination and an apogee of 200,000 km. It has been operating successfully since launch. Another such pair, Interball-Aurora, is still awaiting launch into an orbit with a lower (20,000 km) apogee. The configuration is particularly suited to study the cause-and-effect relationships between the plasma processes in the geomagnetic tail and in the auroral acceleration region.

The Japanese contribution to the IASTP programme, the Geotail spacecraft, has been providing exciting data since its launch in 1992. Geotail is primarily intended to explore the Earth's magnetotail, up to distances of 220 Earth radii, and has shown a richness in structure and dynamics which have changed our views of this region. Closed magnetic structures even in the distant tail appear to be quite common. Plasma measurements show a multitude of regimes, differing in temperatures and flow speeds and directions. One of the most surprising observations is the apparent disappearance of the distant magnetotail at times of prolonged occurrences of northward interplanetary magnetic field. Because of its unique orbit, Geotail has also contributed valuable data on the magnetospheric boundaries. This is particularly true after Geotail started descending to a lower orbit in late 1994. Its present 10 x 30 Earth radii orbit will occasionally skim the Earth's magnetopause and bow shock and be ideally suited to study those boundaries. At the same time, this orbit will also traverse the source regions of the magnetic substorms.

The second NASA IASTP spacecraft, Polar, is scheduled for launch in December 1995. Polar will be placed in a 90 degree inclination elliptical orbit with a 9 Earth radius apogee which during the prime mission will be located over the north pole. Polar will carry out *in situ* studies of the distant polar magnetosphere, but will also investigate the auroral region with its set of imaging instruments.

Also part of the IASTP and a major step for space plasma physics, is the ESA-led Cluster mission, wherein four spacecraft will fly in close formation to study three-dimensional field and plasma structures in the Earth's magnetosphere and its boundaries. In particular, fundamental physics will result from the first use of multi-point measurements in the high latitude magnetosphere. Cluster is to be launched on the first Ariane-5 flight, presently scheduled for the spring of 1996.

The Solar and Heliospheric Observatory (SOHO), which together with Cluster forms the first cornerstone of ESA's Horizon 2000 programme, with its mix of remote sensing and *in situ* measurements, will investigate solar and interplanetary processes, many of which are closely related to those pursued by Cluster and the other IASTP missions. It is scheduled for launch in December 1995.

As is apparent from the new missions already launched or those being readied for launch, the next few years should provide great advances in the understanding of space plasmas. Ground-based observations of various kinds are planned in conjunction with those missions and will contribute significantly to the understanding, particularly with regard to global questions, as will instruments carried on balloons and sub-orbital rocket flights.

V. RESEARCH IN ASTROPHYSICS FROM SPACE

A. Astronomy

The needs of astronomy can only be met by access to the entire electromagnetic spectrum from the radio to the gamma-ray range. These needs differ from those of many other disciplines because large parts of the spectrum do not penetrate the atmosphere of the Earth and observations are therefore literally impossible unless the relevant instruments are placed above the Earth's atmosphere. In addition, even for wavelengths that can reach Earth, the distorting effects of the atmosphere mean that substantial performance gains can be achieved with space-based instruments, as is now being demonstrated by the use of the HST. A considerable degree of complementarity is thus implied between ground-based and space-based astronomy. However, given the current high cost and extreme shortage of funds for space-based instruments, it is increasingly important to establish that access to space is absolutely essential and that the proposed observations cannot be pursued solely with ground-based facilities. As precursors to space missions, it should also be noted that several balloon experiments are on-going, most of which are in the infra-red, hard X-ray and gamma-ray domains. In addition, due to the budgetary pressures mentioned above, there is increasing emphasis on the possibility of using small spacecraft with reduced launch and operations costs. Despite some of the current difficulties with newly developed small launch vehicles, it is clear that consideration will increasingly be given to more modest missions.

An overview of worldwide space programmes in astronomy and astrophysics is summarized in Tables 1 and 2. These tables list the main responsible agency or nation, launch dates (actual or scheduled), and also provide a brief description of the main characteristics of the mission.

A large number of projects and proposals have been submitted to the various agencies. ESA is studying stellar seismology and microwave background missions for the M3 opportunity while an advanced astronomy mission will form part of the extended Horizon 2000 Plus programme. Several interesting mission proposals in all areas of astronomy have been submitted for the NASA Medium Explorer (MIDEX) programme. Summary comments on the content of the tables are presented below.

Gamma Rays

The exciting results currently being obtained by Granat and the Compton Gamma-ray Observatory indicate interesting and complex sources over the whole gamma-ray domain. High energy imaging and spectroscopy instruments together with context instruments for X-ray and optical monitoring, have been selected for the ESA Integral mission.

X-rays

The ROSAT and ASCA spacecraft are currently producing a wealth of remarkable data which are being followed-up in many spectral regions. Several X-ray missions (AXAF, Astro-E, XMM) are in the pipeline for launch around 2000.

UV and Extreme UV

HST has been repaired and now produces excellent data at close to its original design limit. IUE is still operational 16 years after launch. EUVE has completed its survey and now operates in the pointed or observatory mode. The FAUST and ORFEUS missions have been completed while the NASA's FUSE mission is now proceeding in a descoped form.

Visible

As mentioned above, HST is fully operational and will have two new instruments fitted in 1997. In asteroseismology, STARS is being studied by ESA while an advanced astronomy mission has been chosen for study as a cornerstone in the ESA Horizon 2000 plus programme. In parallel, very large ground-based projects are underway in several countries.

Infrared

ISO was scheduled for launch in 1995 and IRTS has been completed. SIRTF (United States) has suffered from some past uncertainties but is still being pursued. A Japanese infrared mission is being considered for flight around 2000. Taking into account the impressive developments of ground-based near-infrared telescopes, the field seems reasonably well covered.

Sub-millimetre

Approved missions include Relict-2 (Russian Federation) and SWAS (United States), a small Explorer. Odin is in phase-B and projects such as AELITA and SMME-SMILS are being considered. FIRST, the largest mission approved in this frequency band, is the fourth of the ESA cornerstones. COBRAS/SAMBA (ESA) is undergoing phase-A study as a follow-up to COBE but with broader scientific objectives. The airborne SOFIA (Germany-United States) should be operational by 2000.

Radio

VSOP and RADIO-ASTRON are the first approved VLBI missions and will open up a new frontier with involvement of the ground-based VLBI arrays. Lower frequencies and longer baselines should be considered in the future.

Complementary Research

In addition to the information from the analysis of photons, astronomers have seriously considered the possibility of using other particles such as neutrinos, gravitons, and charged species (cosmic rays). While neutrino detection, for the time being, appears to be an exclusively ground-based activity, gravitational wave astronomy from space may have considerable potential. A space-based interferometer system is being considered as a future cornerstone mission in the ESA Horizon 2000 Plus programme. Cosmic ray studies, as distinct from investigations of heliospheric modulation, have been reasonably well covered by medium size missions in the past. At present no cosmic ray mission is approved although future projects exist: Astromag (United States), a large superconducting magnet, is being considered as an attached payload for the Space Station. POEMS (United States-France), a Small Explorer mission, is being considered for electron-positron studies.

Conclusions

The state of astrophysical research in general and of the ever increasing part of it performed with space-based instruments continues to be healthy though under increasingly severe budgetary pressures.

Most of the wavelength bands require further space investigation. The electromagnetic spectrum from UV to gamma-ray cannot be explored other than with space-based observatories. Thus, continued access to space is essential for the development of astronomy.

New missions tend to be bigger and more costly and international collaboration and cooperation is therefore essential.

Increasing consideration is being given to the role of small missions. While much of space astronomy requires intrinsically large facilities, technical advances, particularly in on board data processing and storage, will allow modest scale missions to play an increasing role.

Table 1. Astronomy Missions Launched or in Post-Launch Operation

Year	Radio	Sub-mm	Infrared	Visible/ UV	Extreme UV/X-ray	Hard X/ Gamma-
1978			Kuiper	IUE		
1987						Mir/ KVANT
1989						Granat
1990				HST	ROSAT	Ulysses
1991						GRO
1993					EUVE ASCA	
1994				FAUST/ ORFEUS		
1995			IRTS	IEH/ UVSTAR		GGS/Wind

KUIPER	(NASA) Airborne IR Observatory with 91 cm telescope.
IUE	(NASA/ESA/UK) International Ultraviolet Explorer. 45 cm UV telescope for medium-high resolution spectroscopy.
HST	(NASA/ESA) Hubble Space Telescope. 2.4 m telescope for imaging and spectroscopy of galactic and extragalactic sources. Observatory mission.
FAUST	(F/NASA) Wide angle UV camera for imaging and background radiation studies. Flown on Shuttle.
ORFEUS	(D/NASA) 1 m telescope for high sensitivity moderate and high resolution spectroscopy (40-120 nm). Flown on Shuttle.
EUVE	(NASA) Extreme UV Explorer. Sky survey for broad band spectroscopy of bright sources in the range 8-50 nm. EUV spectroscopy. Now in observatory phase.

ROSAT	(D/NASA/UK) Röntgensatellit. Imaging Soft X-ray/EUV telescopes for surveys and pointed observations (0.03 - 2.5 keV). Guest observer programme will continue to 1998.
ASCA	Japan/NASA) High sensitivity imaging and spectroscopy of X-ray sources.
Mir/KVANT	(Russia) Imaging, spectroscopy and timing studies in the band 2-200 keV. Principal investigator mission with guest observer programme.
Granat	(Russia/F) Monitoring and localization of X-ray sources and low energy gamma -ray imaging. Principal Investigator mission with French guest observer programme for the gamma-ray telescope SIGMA.
GRO	(NASA/D) Gamma-Ray Observatory - Compton Observatory. Imaging and broad band spectroscopy (0.1 MeV - 30 GeV).
Ulysses	(ESA/NASA) French gamma-ray burst experiment HGS-OGRE.
IRTS	(Japan) Cooled IR Telescope - 15 cm, for imaging and spectroscopy. Operated successfully for more than 3 weeks and surveyed 10% of the sky.
IEH/UVSTAR	(NASA) UV Spectra from 600 to 1250 Å with two 30 cm telescopes, operated successfully from Shuttle.
GGS/Wind	(NASA) Magnetosphere with Gamma-Ray burst detectors (KONUS and TGRS).

B. Solar Physics

The Sun is the most important and interesting star because of its proximity to Earth. It provides energy, its variability affects the environment, power and communication systems, it provides an essential laboratory for studies of cosmic physical processes and it has almost certainly affected the past climate of Earth. With regard to astronomy, the operation of solar instruments in space eliminates the distorting and absorbing effects of the atmosphere, thus allowing imaging of fine structures and observations of the electromagnetic spectrum beyond the ultraviolet (UV) cutoff. Most of the solar atmosphere, because of the high temperatures reached in the upper chromosphere and corona, is best observed at shorter wavelengths, UV, extreme ultraviolet (EUV) and X-ray. Thus the solar emission is best observed from space.

Table 2. Approved Projects

Year	Radio	Sub-mm	Infrared	Visible/UV	Extreme UV/X-ray	Hard X/ Gamma-ray
1995			ISO			
1996	VSOP	SWAS			SAX	SAX
		RELICT-2			Spectrum X-γ	Spectrum X-γ
					XTE	LEGRI
					EURD	
					HETE	HETE
					SAC-B	Mars 96
1997	RADIO ASTRON	ODIN		HST refurb.		
1998					AXAF	
1999				SpectrumUV	XMM	
					Astro-E	
2001						Integral
2004	FIRST					

VSOP (Japan) 10 m antenna for orbiting VLBI imaging at 1.3, 6 and 18 cm. Observatory in phase C.

Radio (Russia/ESA/United States) 10 m antenna for orbiting VLBI at 1.3, 6, 18 and 92 cm. AstronObservatory in phase C/D.

Relict-2

(Russia) Study of large scale anisotropy and spectrum of 2.7 K cosmic background radiation. Principal Investigator mission in phase C.

SWAS

(NASA) 55 cm off-axis Cassegrain warm telescope for spectroscopic survey of the galactic plane in lines of H_2O, O_2, C I, CO (480-550 GHz). Principal Investigator mission awaiting launch.

ODIN (S/F/Canada/SF) 1.1 m telescope for mm (119 GHz) and sub-mm (420-580 GHz). Interstellar chemistry and atmospheric ozone.

FIRST

(ESA) 3 m warm Cassegrain telescope for high throughput heterodyne and far IR spectroscopy and imaging. Observatory.

ISO	(ESA) 60 cm cooled Cassegrain telescope for spectrophotometry, imaging and spectroscopy of IR sources. Principal Investigator instruments with Observatory operation.
HST	(NASA) Hubble Space Telescope NICMOS (IR) and STIS (Optical/UV) instruments to be installed during refurbishment.
Spectrum/ UV	(Russia/I) Optical/UV telescope - 1.7 m, 90-900 nm, for spectroscopy and wide field imaging.
SAX	(I/NL) Imaging, broadband spectroscopy and long-term monitoring of X-ray sources (0.1-200 keV). Principal Investigator mission awaiting launch.
Spectrum X/γ Ray	(Russia/NASA/ESA) Spectroscopy, imaging, monitoring and polarimetry of X-ray sources. Principal Investigator mission in phase C/D.
XTE	(NASA) Temporal studies and broadband spectroscopy of compact X-ray sources (1-200 keV). Principal Investigator mission awaiting launch.
SAC B	(Argentina/NASA) CCD detector to study the diffuse X-ray background and X-rays from Solar Flares. Primarily an engineering test.
EURD	(E) UV spectrometer on MINISAT-1 (E) to monitor the diffuse background from 30 to 100 nm.
HETE	(NASA) Primarily aimed at gamma ray burst and X-ray transients but also has a UV CCD camera and a French experiment.
AXAF	(NASA) High resolution imaging and spectroscopy of the X-ray sky. Observatory facility.
XMM	(ESA) High throughput spectroscopy and imaging in the soft X-ray range. Observatory in phase B.
Astro-E	(Japan/NASA). High throughput imaging X-ray spectroscopy facility - including a microcalorimeter and CCDs, for the range 0.1 - 10 keV.
LEGRI	(E/UK) Low energy Gamma-Ray instrument on Minisat-1 (E) to cover the range 15-150 keV.

Mars 96(Russia) French Gamma-Ray burst experiment LILAS-2

Integral(ESA) Imaging and spectroscopy from about 5 keV to 10 MeV Phase B

The main problems addressed in space solar physics remain those related to the upward transfer of the mechanical energy resident in the convective motions below the photosphere, and to the conversion of this energy to forms that are responsible for the heating and activity of the corona and the acceleration of the solar wind. Both problems require observations of the solar atmosphere on the smallest possible scale because it is clear that some of the crucial physical processes are very localized. It is also necessary to detect simultaneously the entire solar spectrum in order to encompass all the possible temperature and height regimes of the Sun.

The major solar space missions conducted in the past, such as Skylab (United States), the Solar Maximum Mission (United States) and Hinotori (Japan), have made significant contributions by allowing coordinated studies over a wide range of wavelengths including visible, UV, X-ray and gamma-ray photons. This emphasis on coordination is one of the key elements in most of the major future programs for solar physics. Furthermore, from lengthy experience in solar observation and the need for collaboration with colleagues in many nations to overcome the day/night cycle in gathering data, the solar physics community has a long and successful history of international cooperation which is fully exploited in planning space missions.

1. Currently Operating Solar Programmes

There are two main thrusts to currently operating solar programmes. The first covers the study of solar activity and the drive to understand solar flare phenomena. In addition to important fundamental aspects, this work has the ultimate goal of enabling us to forecast flare and other coronal activity which can strongly influence the interplanetary and terrestrial environment. The second objective is to observe the Sun with instruments which address a broad range of unanswered scientific questions regarding the nature of the inner corona, the extended corona and the acceleration of the solar wind. The high temperature (1-2 million K) of the solar corona remains unexplained while the investigation of the sources of the solar wind is crucial for the understanding of mass loss from the Sun and ultimately for clarifying important features of stellar evolution.

In August 1991, the ISAS (Japan) launched Yohkoh, the only long duration mission totally devoted to solar observations during the current cycle. The four instruments on Yohkoh are designed to study high energy solar flare activity, the global coronal structure and the irradiance variations of the Sun. Yohkoh is carrying the Soft X-Ray Telescope, a collaborative United States-Japanese experiment, which is imaging the soft X-ray corona, and a Bragg crystal spectrometer developed jointly by experimenters in the United Kingdom, United States and Japan. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope providing much better sensitivity and resolution than the imaging detectors previously flown on the Hinotori and Solar Maximum Mission satellites. Higher energy X-rays and gamma rays are also monitored by the Yohkoh instruments provided by Japanese groups.

Yohkoh has produced many new results and has observed thousands of flares. Its excellent spatial and temporal resolution has revealed the highly dynamic nature of the solar corona with changes of the coronal magnetic structures taking place very suddenly. With Yohkoh, the process of magnetic reconnection was for the first time actually observed to occur in solar flares and active regions. Yohkoh has discovered active region brightenings with a frequency of occurrence as a function of their energy which is a continuous extension of the similar distribution for flares. This implies that small events ("microflares") are not over-abundant. This result is important in relation to the problem of heating of the solar atmosphere since it rules out microflares as the source of coronal heating. With the decline of the current solar cycle, much new information has been obtained on the evolution of coronal streamers, the related occurrence of Coronal Mass Ejections (CMEs) and on the nature and evolution of Coronal Holes, the sources of the high speed solar wind streams. This work will continue with combined analysis of Yohkoh and Ulysses data while joint observations by Yohkoh and SOHO will take place following the launch of the latter.

A campaign of simultaneous observations of the Sun was organized to study the geometry of magnetically confined plasmas in the solar atmosphere, which included Yohkoh, the United States Solar Plasma Diagnostic Experiment sounding rocket and several ground-based observatories. The campaign resulted in a very rich data set. Support for Yohkoh operations is planned at least through 2000.

The NASA solar physics programme uses flight opportunities from the Space Shuttle to conduct investigations of the corona with Spartan, a retrievable, autonomous satellite that permits up to two days of solar observing time. A white-light coronagraph and an ultraviolet coronal spectrometer study bulk flow patterns and acceleration mechanisms of the inner solar wind. The instruments undertake UV spectroscopy and white light polarimetry of the extended solar corona from 1.5 to 6 solar radii from Sun centre, thus allowing measurement of temperature, densities and bulk outflow velocities of electrons, protons and several minor ions. The resulting description of the extended corona can be used together with theoretical studies to identify and understand the physical processes involved in solar wind acceleration.

The first Spartan-201 mission flew in April 1993. The second and third missions took place in September 1994 and September 1995 when the ESA/NASA Ulysses spacecraft reached its maximum latitude over the Sun's south and north poles respectively. While Ulysses undertook *in situ* sampling of the solar wind high in the heliosphere above the Sun, Spartan performed remote sensing of the source regions for the same solar wind observed with Ulysses, the first such simultaneous observations. Finally, in 1996, Spartan-201 will underfly the ESA/NASA SOHO in a calibration mission.

Coronas is a series of Russian Federation satellites designed to observe the solar atmosphere from near-Earth orbit, and to observe solar activity and magnetospheric solar effects.

They will carry a number of instruments developed by groups from the Russian Federation, in collaboration with groups from many other countries. The instruments include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as detectors for helioseismology, dedicated to the indirect investigation of the solar interior.

The Solar Station Coronas-I was launched in March 1994. The 11 instruments of the scientific payload covered a wide region of the electromagnetic spectrum from radio to gamma rays. Particles were also detected. The main instruments are an imaging X-ray telescope and spectroheliograph (6 intervals in 2-304 Å spectral range) having spatial resolution of a few arcseconds, an optical photometer for measuring solar oscillations, a radiospectrometer and a set of hard X-ray and gamma- spectrometers from 1-2 MeV.

While no hardware collaboration existed between United States and the Russian Space Agency for the Coronas programme, a Participating Scientist Programme will be supported in 1996 for the encouragement of Russian Federation-United States cooperation in operations and data analysis for this mission.

Currently operating missions which are not primarily dedicated to solar physics but are nevertheless of special importance for solar studies, include Ulysses, Granat and the Compton Gamma Ray Observatory (GRO).

Ulysses, launched in October 1990, is an exploratory mission carried out jointly by ESA and NASA. Its primary objective is the study of the interplanetary medium and solar wind as a function of heliolatitude. The solar physics objectives of Ulysses encompass the study of the structure of the interface between the Sun and the solar wind/interplanetary magnetic field, solar radio bursts, solar X-rays and solar cosmic rays out of the ecliptic plane. In September 1994, after a journey of almost four years, Ulysses reached its maximum latitude during the first-ever pass over the south pole of the Sun. Ulysses is spending a total of 234 days above 70 degrees latitude during its first polar pass. The second polar pass, over the north pole, occurred on 31 July 1995. Ulysses has already sent back a wealth of extremely valuable information from the polar regions on the properties of the high-latitude solar wind and interplanetary magnetic field. The acceleration of energetic particles, at large radial distances and high latitudes in regions where co-rotating solar magnetic fields interact, has been studied in detail.

The main objective of the Granat satellite, launched by the Russian Federation in September 1989, is the mapping of the gamma-ray sky. It has observed over a hundred high-energy solar flares in the energy range from 100 keV to 100 MeV. Several gamma ray flares have substantial emission above 10 MeV. The 2.23 MeV line resulting from the deuterium synthesis reaction during solar flares is also detected. These data can address the problem of the directivity of the solar high-energy emission.

The Compton GRO, launched in 1991, is well-suited for observations of the solar X and gamma radiation and accelerated neutrons which are the most energetic phenomena taking place during solar flares. The flare emission is observed in the energy range from 50 to 1000 keV and above 20 MeV. The GRO data allow an extremely accurate measure of the energy spectrum of the non-thermal radiation of the Sun. Many important results have emerged including the direct demonstration by timing that non-thermal electrons move from the coronal flare release site to impact the Chromosphere.

2. Missions Currently Under Development

The joint ESA-NASA SOHO spacecraft was scheduled for a November 1995 launch. SOHO is one of the most ambitious solar physics space science missions developed so far and its scientific payload consists of 11 instruments, including six built by ESA in collaboration with groups in the United States. These instruments will study the Sun, from the centre, by means of helioseismology, to the outer atmosphere, by remote sensing in the visible and UV. The solar wind will be simultaneously probed at 1 AU by *in situ* studies. SOHO will thus study the interior and the atmosphere of the quiet Sun addressing the problems of the internal structure below the photosphere, of the heating and generation of the corona, and of the acceleration and composition of the solar wind. Special emphasis is placed on high spectral/spatial resolution of the inner corona and on observations of the extended corona to 30 solar radii.

The SOHO spacecraft will be placed at the Lagrangian point between the Earth and the Sun to avoid the confusing effect of orbital velocity present in low Earth orbiting missions. From this unique vantage point, 1.5 million km in front of the Earth, SOHO should have an unprecedented view of solar phenomena and is expected to clarify the main unsolved problems of our nearby star. The ESA-NASA cooperation in SOHO includes the staffing of a common operations center at NASA/Goddard Space Flight Center for day-to-day operational decisions and collaborative research. The SOHO scientific data will be maintained in four archives, one at NASA Goddard and three in Europe, for a period of 10 years from the end of the mission. This will open data to and facilitate access by the widest possible community.

The second Coronas station is currently under development in Russia. Named Coronas-F, its launch is scheduled in 1996. The payload will include improved versions of the instruments of Coronas-I, with increased resolution of the X-ray telescope of 700 km or less on the Sun. Coronas-F will also observe spectral lines in the region 3-7 Å. The third solar mission in the Coronas program is Foton which will include a large solar gamma-ray telescope.

The Transition Region and Coronal Explorer spacecraft (TRACE), a NASA small Explorer mission, will be launched in late 1997 into a Sun-synchronous orbit to allow eight months of continuous solar observation. It will be operated in coordination with Yohkoh and SOHO. The objective of the TRACE mission is to observe directly the connections between the small-scale features that characterize the photospheric magnetic field and the larger scale structures that are seen in the solar corona thus pursuing the discovery by Yohkoh that the corona is a continuously dynamic atmosphere which is responding to impulses from the photosphere. TRACE will survey this connection from the photosphere into the corona, with unsurpassed temporal and spatial resolution (about 400 kilometers on the solar surface). For this reason, TRACE is expected to make major contributions to our understanding of the mechanism of coronal heating. The

TRACE instrument is designed to isolate narrow UV and EUV spectral bands containing emission lines formed in the chromosphere, transition region and corona. TRACE is an open mission and all data and related analysis software will be freely available to the entire solar physics community.

The Satellite de Aplicaciones Cientificas-B (SAC-B), is Argentina's first satellite mission. It has been developed in collaboration with NASA and with the participation of the Brazilian and Italian space agencies and was scheduled for launch in 1995. SAC-B will carry a detector suite to study X-ray emissions from solar flares in the 2 to 300 keV energy range with spectral resolution of up to 1 keV at low energies and a temporal resolution of few tens of milliseconds. The instruments are built by CONAE (the Argentine space agency) and NASA's Goddard Space Flight Center.

3. Balloon Programmes

Several countries have programmes of balloon observations with instruments dedicated to flare physics. The NASA programme includes a long-duration Antarctic balloon investigation, the Flare Genesis Project. Flare Genesis, to fly in December 1995, seeks to break the spatial resolution barrier of ground-based observations using an 80 cm telescope and a vector magnetograph.

As an intermediate experiment aimed to the development of the Space Solar Telescope (SST) in China, a balloon-borne solar telescope with 80 cm aperture size has been approved and is now being manufactured. The balloon flight is being designed to test the SST system and all related subsystems and to observe at high resolution the fine structure of the magnetic fields. The balloon-borne telescope will be launched in 1996.

4. Future Solar Programmes

Future solar space missions continue to focus on understanding the problem of chromospheric and coronal heating, namely the coupling of sources of energy in coronal activity with structures and changes of magnetic fields and plasma motions in the solar outer atmosphere. Significant advances in this field require major improvement in the resolution of the instruments and the use of stereoscopic techniques to define the geometry of the magnetic confinement of the plasma in the solar atmosphere.

The United States Air Force (USAF) is studying an instrument called the Solar Mass Ejection Imager (SMEI). Its goal would be to provide advance warning of the arrival at Earth of solar transient disturbances. It would also be able to map the mass ejection in three dimensions. If work proceeds, this mission could fly in the Yohkoh and SOHO time frames for complimentary studies of the extended solar corona.

The High Energy Solar Imager (HESI) is a candidate in the NASA Medium Explorer programme. It will investigate particle acceleration in solar flares during the 2001 maximum.

Suggested instruments involve imaging spectroscopy in hard X-rays and gamma-rays.

Following the highly successful Hinotori and Yohkoh solar missions launched by ISAS (Japan), the Japanese solar physics community is evaluating a further Sun-observing satellite. The mission, Solar-B, would be launched by ISAS around 2003 and could involve teaming between the communities in Japan, the United Kingdom and the United States. The model payload includes an optical telescope capable of making photospheric images with a spatial resolution of 200 kilometers on the solar surface and of measuring magnetic and velocity fields in the photosphere, a X-ray imager for the diagnosis of coronal plasmas having temperature of 0.5 to 10 million K. Line broadening in transition regions and coronal emission lines, which may be manifestations of energy input into the corona, can be observed with an EUV imaging spectrometer. A Sun-synchronous orbit will be chosen to minimize the effects of observing time gaps and of line shifts due to the motion of the spacecraft.

China in 1992 proposed the development of the SST. The telescope system will consists of a diffraction limited optical telescope with a 1 m aperture, spectrographs, and attached telescopes for the UV, soft and hard X-rays. The satellite carrying the telescope will be placed in a circular polar orbit of 500 km. Launch is planned in 2001-2002, around the maximum of the next solar cycle. The major scientific targets are to achieve a breakthrough in solar physics by coordinated high-resolution observations of the magnetohydrodynamic processes in the solar atmosphere. The telescope will obtain two dimensional spectra, magnetic vector fields, velocity fields and images in the visible, UV and X-ray spectral ranges.

The Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy (SIMURIS) was studied by ESA in the framework of the Space Station Attached Payloads programme and recommended for a second phase of study in 1992. Uncertainties regarding the Space Station programme have delayed the start of this work, though specific studies were undertaken for the accommodation of a reduced version of SIMURIS on the External Viewing Platform of the Columbus Module. The thrust of SIMURIS is for ultra-high spectral, temporal and spatial resolution to investigate the very fine structure of the Sun. SIMURIS can be considered a unique mission capable of observations at the same spatial scale as some of the processes occurring in the solar atmosphere, smaller than 0.1 arcsec or 70 km on the Sun. Besides its temporal and spectral coverage, the SIMURIS Mission proposes a UV imaging interferometer from 1175 Å to 2800 Å with ultrahigh spatial (20 km on the Sun), spectral and temporal (50 ms) resolutions. The interferometric co-phasing technique has been proven in the laboratory and could be applied to future larger and possibly lunar-based interferometric missions.

A cooperative effort among ESA, Japan, the Russian Federation and the United States is proceeding toward the approval of a heliospheric probe mission consisting of two spacecraft to graze the Sun's corona at about 4 and 10 radii. These spacecraft would carry a variety of miniaturized *in situ* instruments and imagers for testing all of our current beliefs concerning the Sun's outer atmosphere some time after 2000.

ESA is studying the possibility of flying several solar instruments, some of which have been developed for the EURECA platform, on the International Space Station. These instruments would form part of the European external payload foreseen for the station. They include systems devoted to the study of solar variability, mainly at UV wavelengths, which is of particular importance for the effect on Earth's atmosphere.

As described above, solar physics plans involve extensive international cooperation and a rich variety of research goals over the next decade. With the advent of new communications technology, the longstanding tradition of such cooperation in solar research will be further strengthened in the future.

VI. LIFE SCIENCES AND SPACE RESEARCH

The scientific community involved in space life sciences research has been very active in the 1994-1995 period. Many new results have been obtained in all branches of this wide and interdisciplinary field, which ranges from gravitational and radiation biology to planetary biology, studies of the origins of life, exobiology and ecosystem studies. It is becoming more obvious that fruitful developments in the area of life sciences can be achieved through space experimentation. Many opportunities have been recently available to the life science community for space research, such as Spacelab IML-1, and Biopan-1. They have provided new data of great importance for the understanding of life, its behaviour in microgravity, its origin and evolution on Earth, and its possible occurrence elsewhere in the universe. These opportunities, together with the many others which can be foreseen from the future Space Station and other planned space missions, have attracted a large number of young scientists from many countries. This is a good sign that a new generation of space life scientists is growing and will be able to ensure continued progress in this field in the future.

A. Radiation Biology

An improved understanding of the biological damage caused by HZE particles of cosmic radiation is highly important for a precise estimation of the radiation risk in manned space flights. Presently, radiation protection is based on concepts that have been developed for normal terrestrial conditions dealing mostly with low doses of sparsely ionizing radiation as is the case for people working in medicine or with elevated doses of neutrons in nuclear reactors. During space flights, the occurrence of HZE particles is low, but the doses concentrated in the centre of one individual track exceed the low dose approximation of conventional radiation protection by many orders of magnitude. Therefore, the concept of conventional radiation protection must be questioned and alternative concepts should be considered.

There are two basic radiobiological questions for manned space flights. First, what radiation exposure is expected for specific flight outside the magnetic shielding of the Earth? Secondly, what are the biological consequences in terms of early and late effects for humans exposed to this radiation?

The question of radiation exposure contains the problem of the radiation quality coming from the primary source, i.e. the radiation originating from solar flares and consisting mostly of protons and to some extent of helium ions, fluctuating in more or less regular cycles with a period of 11 years. In addition, the continuous exposure to cosmic radiation, which is lower in intensity but much higher in atomic number ranging up to heavy ions such as iron, has to be considered. Because of the higher biological efficiency of these heavy ions, their abundance and energy distribution should be known with high accuracy. In practice, most of the time the astronauts will be inside their spacecraft and the quality of the radiation will be changed by the nuclear reactions of the primary beam with the shielding of the spacecraft.

The second question concerns the biological action of the primary radiation in case of exposure outside the spacecraft and of the modified radiation in case of exposure inside the spacecraft. Again, for the answer to this question there are two levels of accuracy. The first level assumes that there is no change in the radiobiological consequences whether the exposure was performed on Earth or under microgravity conditions. This means, that all the data obtained at heavy ion accelerators can be transferred to space without any modification. The second order of accuracy asks whether the microgravity conditions might influence the biological response in any way or not.

For both questions, the primary particle exposure and the biological response, significant progress has been made in the reporting period. Measurements of the energy and atomic number spectrum have been performed routinely in all space missions. Transport codes, including the nuclear reactions as measured in accelerator experiments, are able to calculate the radiation quality to a large extent and with good accuracy behind various types of shielding material. Therefore, the modification of the radiation by the different shielding material can be predicted when the primary radiation is known.

The estimation of the biological response however is more difficult. Even the assumption that microgravity does not modify the radiation response implies that the biological effect should be known for the complete energy spectrum of the lighter ions and for many different biological systems and tissues. This is not the case. For the important long-term effects such as cancer induction and genetic alterations, no solid database exists. In accelerator experiments, significant progress has been made to create a solid database, but an accurate set of experiments only exists for a few modalities. For a more detailed knowledge, further sets of experiments are required, especially those concerned with genetic alteration. The question of the interaction of microgravity and biology has been tackled in a few exploring experiments. The very preliminary results of space radiobiology experiments show a very controversial outcome. At the molecular level, i.e. DNA damage and repair, there seems to be no influence of gravitational parameters. However, at more complex organization levels, there are still the experiments reporting differences between Earth and space conditions.

In summary, the biological hazard of cosmic and solar radiation can be predicted to an extent that is not satisfactory for long-term space missions. A deeper understanding of the biological action of particles concerning long term effects (genetic alteration, cancer induction) is needed.

B. Gravitational Biology

There are a number of difficult problems inherent in the performance of experiments in gravitational and space biology. Five of these are described below.

Launcher systems and spacecraft impose constraints that result in experiment scenarios which are completely different from laboratory practice. This will not be different in a space station environment. Safety requirements, environmental loads, automation and functioning under conditions of microgravity result in the development of experiment hardware that bear little resemblance to normal laboratory hardware. Biological experiments require elaborate pre-experiment preparation and post-experiment analysis which is normally performed by trained specialists applying a variety of ground-based techniques. The performance of these activities in space is close to impossible. The number of experiments performed in one ground-based institute in one week is typically more than what the whole biological science community can do in space in one year. Near-term continuity of opportunities for space biological investigations cannot be provided to any individual research group in the field.

The latter two problems may be the most important ones hindering the advancement of research in space life science. In the era of Spacelab, which will end in 1998, a wealth of new, but diverse observations have been made and many lessons were learned. Specific areas in biology and human physiology now require dedicated research efforts to elucidate the mechanisms that are at the basis of these observations. The pace of experimentation necessary to meet these objectives would have to be increased considerably.

It is not obvious that this will be achieved by the utilization of the Space Station due to the first three problems mentioned above. A step forward will be made with respect to the study of long-term effects in human biology, animal biology and plant biology. However, probing underlying mechanisms often requires many, relatively short-duration experiments for which dedicated launcher and spacecraft systems will be needed.

In addition to the space-borne experiments, facilities exist, and other facilities could be developed, that allow a considerable part of gravity-related biological experiments to be performed on ground. Once the investments in these facilities have been made, their utilization can take an increasing part of the research in a very cost-effective manner.

As was also mentioned in the 1994 report, to establish the necessary continuity in space and gravitational biology it appears to be of great importance to maintain and develop a variety of spacecraft meeting specific requirements in the discipline concerned, and to develop continuous programmes in gravity-related ground-based research. Only by establishing a strong user community having continuous access to dedicated ground facilities can it be expected that the most relevant scientific investigation will be performed in space, both in a space station environment and in other spacecraft.

The concerns mentioned above are a consequence of the success encountered in space biology. The adaptations observed in the human body, the better understanding of gravitropism reactions in plants, the influences on fundamental molecular processes in the living cell, and the remarkable regulation in developing animal systems all generate many more questions of high scientific interest. The existing capacity to tackle these questions is insufficient now and will be insufficient in the foreseeable future unless a considerable effort is made to strongly develop the continuous ground-based portion of the research.

C. Planetary Biology and Origins of Life

Two major sources of complex organic compounds that have enabled the origin of life on Earth are thought to have originated through synthesis on Earth and delivery from space. In 1995 there was significant progress achieved in understanding the potential importance of both mechanisms. With the recent discovery of pathways for the synthesis of pyrimidine bases from urea, all four RNA nucleotide bases can now be synthesized under plausible simulated early Earth conditions. In addition, simple organic molecules exposed to the space environment have been shown to polymerize. Furthermore, processing in material under simulated cometary conditions have produced complex compounds spectrally similar to organics observed in space. A source of pre-biotic material may exist at the icy fringe of the solar system, outside our furthest planet from the Sun. A population of over 200 million comets has been detected and represents a reservoir of pre-biotic compounds that may have remained essentially unchanged since our solar system began over 4.5 billion years ago.

The survival of microorganisms in space is relevant to understanding the potential for contamination in the environment and also the possibility of transferring life from one planet to another. Microorganisms have a temperature dependent response to UV radiation, which can be compounded by other factors of the space environment. The variable response to radiation may provide clues as to the mechanism of genetic damage. Even the most hardy micro-organism seems to be dependent on protection from the radiation environment in space. Some microbes can survive with shielding, whether with a thin filter in space or a layer of ozone on our early planet.

The concept that the present DNA protein-based life on Earth may have been preceded by organisms using RNA for both genetic and metabolic functions has gained credence with recent laboratory demonstrations of enhanced RNA catalytic capabilities. Ribozymes (catalytic RNA) evolved in test tubes have developed the ability to cleave amide bonds, a capability related to protein formation, and are capable of non-nucleotide bond formation and of self-alkylation, reactions analogous to what would be expected to be common in a RNA world.

With Earth as the only known example, the possibility that life may have evolved on another planet in our solar system holds great promise of furthering our understanding of the mechanisms for the origins of life and to the potential distribution of life in the universe. The expectations for life having evolved on Mars are only enhanced by the recent analysis of Martian meteorites finding minerals which form in aqueous environments. Strategies for Mars exploration now recognize the potential significance of Mars as a repository of new information about the origin and evolution of life, and underscores the purpose of planetary protection guidelines, for both forward and back contamination.

D. Natural and Artificial Ecosystems

One rationale for this research field being is the fact that long-term space exploration will require regeneration of materials used for life support, and the most fully developed regenerative systems known thus far are biological ones. Thus, higher plants harvest light to power the conversion of simple gases, water and minerals into oxygen and food. The development of bioregenerative systems for space life support has been a topic of research interest for a number of years, and the resemblance of such systems to natural ecosystems is strong enough that they have been dubbed artificial ecosystems.

A second rationale has been the increasing interest in global ecology and the impact of human activities. In many cases, the changes that are occurring in the enormous Earth ecosystem cannot be observed except from space. As a consequence, Earth observation has become a significant scientific technological and political issue, and one that can be fully addressed only through a combination of ground and space research.

A third rationale for these studies lies in a research area, comparisons between natural and artificial ecosystems, that was expected to grow more rapidly over the past few years than it has. Because of the difficulties in conducting experiments in natural ecosystems, it was assumed that artificial systems would be ideal for evaluating the impact and consequences of various kinds of change. To date, only limited interest has been raised in this potentially fruitful area of research; it appears likely, however, that as technological capabilities for measurement and analysis of system parameters increase, so will interest in the approach. Pertinent reviews of this topic may be found in the 21 July 1995 issue of Science (see for example, J. H. Lawton, vol. 269, pp. 328-331, 1995).

The two items that would be the most important this year for COSPAR Subcommission F4 would be the start of closed system testing for CELSS at NASA's Johnson Space Center and the conversion of Biosphere-2 for environmental systems studies.

VII. GRAVITATIONAL EFFECTS IN FLUID AND MATERIALS SCIENCE

A wealth of information has been gained in the past two years through microgravity experimentation in the materials science area. Significant research has been carried out in the areas of materials, fluids, and combustion. Some of the outstanding accomplishments made are summarized below.

A. Materials Science

Experimentation on Space Shuttle flight STS-62 provided exciting new data concerning dendritic solidification. This project studied the tiny crystalline structures or dendrites, which form during solidification of metal alloys during manufacture. Since most metals solidify dendritically, a good fundamental understanding of dendritic growth is imperative because of the possible gains in alloy performance and reductions in manufacturing costs. Experimental results provided data over a range of undercoolings and growth velocities, that can not be properly monitored on Earth. The findings indicate that current theories may need significant modification.

New information concerning thermophysical properties of metallic glasses and undercooled alloys was obtained during the IML-2 flight in July 1994. Initial results from these experiments indicate a much larger variation in total hemispherical emissivity of an undercooled liquid than has been usually assumed. Results indicate that seven previous assumptions normally used in this field are invalid.

Experimentation on cadmium-zinc-telluride has revealed a dramatic difference in structural perfection between ground samples and samples produced under identical conditions in space. Space results easily equalled the best ground grown crystals produced to date. Defect densities were reduced by levels of almost 100, producing the lowest defect density materials available.

Experimentation on HgZnTe semiconductor ingots has demonstrated that directional solidification of a portion of the sample on Earth followed by quenching and then backmelting to the original solidification front position is a valid means of reducing processing time in orbit. This approach avoids the lengthy period necessary to reach steady state growth conditions in orbit. In other experimentation HgCdTe crystals approximately 15 cm in length have been grown using directional solidification over an 11 day period.

Interesting results were obtained from directional solidification of selenium doped gallium arsenide crystals carried out in space. Composition measurements indicated that diffusion controlled growth conditions were achieved initially, but that after approximately 1 cm of growth, conditions changed to complete mixing. Correlation of the results with acceleration data is underway.

Containerless processing techniques have been utilized to determine viscosities and surface tensions of undercooled metallic melts. This work should allow determination of the temperature dependence of these parameters which is currently a controversy.

Research carried out on NASA's USMP-2 mission utilizing the French designed MEPHISTO apparatus will permit comparison of the fundamental aspects of solidification with and without a strong influence of atomic attachment kinetics. Results should eventually lead to determination of the correlation between morphological stability and interface kinetics

Liquid phase sintering experiments carried out on IML-2 allowed study of this processing technique without the separation, settling, and other gravity induced complications seen during ground based processing. An improved understanding of this commercially significant process has been gained as a result.

Great advances have also been made in the study of fluids near their critical point. Most of this research has been carried out with helium and has permitted determination of thermal conductivities, heat capacities, and decay rates of critical density fluctuations near the liquid-vapour critical point.

Work on Al_2O_3 dispersion strengthened superalloys carried out on the second German Spacelab D-2 mission has provided an improved understanding of the behaviour of small particles in a melt. The results obtained under microgravity conditions indicated that agglomeration of nm-sized particles is independent of the metal-ceramic wetting behavior. These results match some of the theoretical work carried out in this important field.

Work carried out on the Al-Al_3Ni eutectic system has determined the influence of gravity level on metals processed at rates approaching those utilized industrially. Dramatic differences in eutectic spacings, cell shapes and uniformity were observed between segments of samples solidified under low-g conditions and one-g conditions.

Work on gallium arsenide crystal growth from a metallic solution under microgravity has provided interesting results. This research, which was carried out using sounding rockets and on the D-2 mission, looked at the effect of reducing both gravity-induced convection and surface tension-induced convection. The growth method was a simplified liquid phase epitaxy technique which housed the melt in a GaAs "cube." New insight was gained into the growth mechanisms in the absence of convection under u-g conditions.

Other work has focused on utilizing the floating zone technique for processing gallium arsenide under microgravity conditions. The use of this material for opto-electronic devices is dependent upon the production of low defect density single crystals for use as high quality substrates. The crucible-free floating zone technique is an interesting approach for this application because impurities and structural defects induced by the direct contact of the melt and crystal with the container are avoided. Work carried out during the D-2 mission was successful at producing GaAs crystals 20 mm in diameter. This size is considerably larger than any crystals grown previously. The experiments were carried out utilizing the PARELLI mirror furnace.

Research on the EURECA carrier and on the D-2 mission looked at the problem of crucible sample interactions and their effect on the structure of several semiconductors. In these studies, a novel approach was utilized in which advantage was taken of the de-wetting of a rough crucible surface by semiconductors. Using this approach, contact between the sample material and crucible is minimized reducing sample-crucible interactions. New theoretical and practical conclusions were drawn concerning sample-crucible interactions.

B. Combustion Science

In the field of combustion science, significant progress has been made on determination of the controlling mechanisms of flames spreading over fuels in the absence of buoyant or externally imposed gas-phase flow. Microgravity experimentation has allowed researchers to uncover the underlying physics and increase the fundamental understanding of the mechanisms that cause flames to propagate over solid fuels under a low velocity flow of oxidizer.

Gas jet diffusion flames have been studied for laminar, transitional and turbulent cases. Sooting effects have been studied with emphasis on burning rate, flume dynamics extinction disruption, and soot particle dynamics. Other research has focused on the mechanisms of smoldering combustion in microgravity and on droplet burning.

Work utilizing the 10 second drop shaft in Hokkaido, Japan, has studied details of flame propagation in a combustible particle cloud under microgravity. Significant advances have been made in understanding the commercially significant combustion process.

Work in smoldering combustion has concentrated on obtaining basic information about smolder controlling mechanisms and on the potential onset of a smolder-initiated fire under microgravity conditions. Experiments have been carried out using drop towers, parabolic flight aircraft, and the Space Shuttle. As predicted, gravity was found to play a major role in the competition between the supply of oxidizer to and the transfer of heat to and from the smolder zone. Process control was found to vary from limited oxygen supply to limited heat transfer as conditions were varied.

New UV-Laser diagnostic tools should help in future interpretations of combustion experimentation carried out under low gravity conditions. These techniques make it possible to measure temperatures, species concentrations and velocities with high resolution in a non-intrusive manner. These parameters can be made simultaneously in a two-dimensional plane formed by a light sheet of the laser beam. Preliminary results have been obtained from drop tower tests.

Experimental studies have been carried out on a laminar diffusion flame established over a flat horizontal burner. The goal of this work was to provide further understanding of the transport mechanisms controlling a diffusion flame with particular interest in the role of buoyancy. In normal gravity the flame is made up of a boundary layer region where inertia dominates and a plume region where buoyancy dominates. When gravity is eliminated, the plume region disappears and the overall flow velocity is reduced to forced flow. Results have been modelled and confirm the important role of gravity in determination of the characteristics of a diffusion flame.

C. Fluid Science

The last few years have provided several new opportunities for the study of the behaviour of fluids under microgravity conditions. This is a critically important area for the advancement of materials science because of the dramatic influence fluid flow can have on the processing of a material.

Several studies have been carried out involving the stability of liquid bridges. These studies mimic the conditions found during zone melting and solidification of alloys and have been quite helpful in identifying conditions controlling stability. For example, it has been found that oscillations of the columns can be easily induced and under some conditions, six resonances can be identified. New techniques have been developed to predict these resonances. Work has now expanded to include the analysis of the vibrated flows induced by these oscillations.

Other work has focused on convection in containers. While buoyancy driven flow is dramatically reduced by processing under microgravity conditions, other forms of flow may be quite significant. One of the most important is surface tension driven flow or Marangoni convection. The Surface Tension Driven Convection experiment carried out on USML-1 studied flows generated in an open container of silicone oil when the free surface was heated by a CO_2 laser. Good agreement was obtained between the calculated and measured flow fields in this experiment. It was interesting that no oscillatory thermocapillary flow was found in this experiment despite the fact that conditions were utilized where oscillatory flow has been observed during ground tests.

Work carried out during the D-2 mission studied the onset of oscillatory Marangoni flow in liquid bridges. This experiment allowed measurement of the frequency and amplitude of temperature oscillations near the onset of Marangoni instability.

Other work has investigated the peculiar behaviour of two drops of the same fluid when brought together under microgravity conditions. It has been found that if the temperature difference above some critical value exists between the drops, they will not coalesce even when squeezed against each other. This phenomenon seems to be associated with the motion induced by surface tension imbalance due to temperature gradients along the droplet's surfaces (Marangoni flows). Additional work is being carried out in this area.

Other experiments involving liquid droplets have focused on the migration of droplets in an immiscible liquid system. In these experiments, droplets of one liquid are suspended in another liquid which is subjected to a temperature gradient. The variation in temperature across the droplet surface results in a surface tension driven flow which results in droplet migration. The velocities of these droplets have been found to be in good agreement with the theory of Young et al.

Obviously, only a limited number of the experiments carried out under microgravity conditions can be discussed here. However, it should be apparent that a great deal has been accomplished over the past two years in the microgravity sciences area. Major advances have been made and new questions have arisen. The next few years should prove most interesting due to the significant advances expected in the materials science area due to the opportunity to carry out experimentation under the low gravity conditions of space.

VIII. SATELLITE DYNAMICS

The field of satellite dynamics includes research that focuses on topics in satellite orbit determination and analysis as it is applied in obtaining scientific knowledge about the Earth, the Moon, the planets, and other celestial bodies, and their environments. These topics include: (1) precise orbit computation including state-of-the-art modelling techniques; (2) real- and near-real-time orbit determination as well as post-fact analysis based on tracking systems such as GPS, DORIS, PRARE, TDRSS, space-borne laser and microwave systems, and ground-based SLR; (3) numerical models for the description of non-conservative forces acting on current spacecraft such as LAGEOS I and II, Topex/Poseidon, ERS-1 and 2, SPOT, Starlette, Stella, GFZ-1, Etalon-I and -II, and the GPS and GLONASS constellations; (4) precision orbit techniques and comparisons specific to altimetric and topographic missions current and planned for the future, and; (5) the study of the requirements and novel orbit determination techniques for all proposed future satellites which will perform a variety of missions to the various celestial bodies. These topics are discussed by members of the international scientific community at the Technical Panel for Satellite Dynamics meetings which are held during the COSPAR Scientific Assemblies.

A. New Geodetic Satellites

The German GFZ-1, laser retroreflector, satellite was launched from the Russian Mir Space Station into a 398 km orbit in April, 1995. This is the lowest altitude geodetic satellite ever flown and its lifetime is expected to be about four years. This passive SLR satellite is being tracked by the SLR global network. The second in a series of altimetric satellites, ERS-2, was also launched in 1995 and all instruments are operating successfully, including the PRARE tracking system. ERS-2 will operate simultaneously with its sister spacecraft ERS-1 for an extended period of time to cross-calibrate their instruments and to perform in-tandem SAR experiments. Microlab-1 was launched from a Pegasus along with two commercial satellite payloads. Microlab-1 is carrying a space-qualified Turbo Rogue GPS receiver that is being successfully used to monitor temperature and water vapour in the atmosphere by means of occultation observations of the GPS satellites over the Earth limb. The GPS tracking data will also be used for gravity field improvement. The German Space Agency's CHAMP satellite is scheduled for launch into a near-polar 500 km orbit in late 1998. Its main objective is to precisely recover the long wavelength features of the Earth's gravity field. In addition it will be used for meteorology and climate studies by radio occultation measurements. Instrumentation on CHAMP will include a PRARE receiver, laser retroreflector, a GPS receiver and an accelerometer.

B. Satellite Orbit and Geopotential Models

A joint effort has been started between GSFC and DMA for an improved 360 x 360 degree Earth gravity model with the goal of a geoid accuracy between 0.5-1.0 m. Investigations of small perturbations experienced by the LAGEOS spacecraft include the possible effects of volcanic aerosols, Earth albedo, micro-meteorite impact, and the thermal properties of the spacecraft. Dual crossover techniques have been developed to assess the refinement of ERS-1, ERS-2, and Topex/Poseidon orbits using altimeter data from these satellites.

C. Reference Frames

IERS is now adding the GPS and DORIS networks to the SLR and VLBI definition of the annual terrestrial reference frame solutions and is considering the adoption of the solution for periods longer than one year. A revised set of standards was published in 1995 incorporating the latest improvements in the geophysical models, many being the products of successful space missions such as the LAGEOS I and II, Starlette, Stella, ERS-1, and above all the Topex/Poseidon oceanographic altimeter mission.

D. GPS Applications

The global GPS network has grown considerably during 1995. As country-wide dense networks are established, they are being included in the global frame in a sequential manner. The International GPS Service is contemplating other uses of the data, including tomographic mapping of the atmosphere, both troposphere and ionosphere. The Russian Glonass constellation has added six more spacecraft in 1995 and is nearly complete. It is expected that in the near future the remaining spacecraft will complete the constellation. A Global Navigation Satellite System (GNSS) to develop technologies that will ensure that data from the GPS and Glonass systems will be available for civilian use on a reliable basis and will provide the requisite precision. Improvement in the orbit determination accuracy of GPS spacecraft carrying laser retroreflectors have been made through a campaign conducted with the Global Laser Tracking Network.

E. Satellite Missions to the Moon, Mars, and the Asteroids

A 50th degree and order gravity field model has been developed to support the Mars Global Surveyor Mission. Reduction of all Viking-I and -II and Mariner-9 Doppler radio tracking data was made which avoided singularities in the inversion process. A 90th degree and order gravity field model has been estimated using all the Pioneer Venus Orbiter (~15 years) and all the Magellan radio tracking data. The Venusian ephemeris has been estimated over this period to be accurate to 20 m. A new model of the lunar gravity potential has been developed complete to 70th degree and order and includes all available historical data from the Lunar Orbiters 1 through 5, as well as from the Clementine spacecraft. A new lunar mission, Lunar Prospector, a NASA Discovery mission, will be launched October 1997. It will be a 100 km circular polar orbiter, having a one year operational lifetime. Two Mars missions are scheduled for launch in 1996. Global Surveyor is a replacement for the Mars Observer spacecraft, which was lost in

1993. It will carry four of the Mars Observer instruments, including the Mars Observer Camera, the Thermal Emission Spectrometer, the Magnetometer, and the Mars Orbiting Laser Altimeter. Mars Pathfinder will also be launched in 1996 and will arrive at Mars in June 1997. It will deploy a satellite to land on the surface of the planet in the Ares Vallis region. The data will be used to study the dynamics of Mars, including determination of the planet's precession rate and moment of inertia, and changes in the length of a Martian day. The Pathfinder data will be combined with ranging data to the Viking satellites placed on the surface of Mars in the 1970s. NEAR is scheduled for launch in 1996 and will fly by asteroid 253 Mathilde on June 27, 1997. An Earth fly-by is scheduled on January 22, 1998, and rendezvous and arrival at 433 Eros will occur in January-February 1999. Instruments on NEAR include: multispectral imager, near-infrared spectrometer, X-ray and gamma ray spectrometer, laser altimeter and magnetometer.

IX. SCIENTIFIC BALLOONING

Recent activities in the area of scientific ballooning are characterized by a continued interest in long-duration flights and developments towards the improvement of balloon systems and materials for this purpose. Some long-duration flights have been carried out, particularly in the Antarctic region, but also from other locations, and numerous future campaigns are in preparation. Balloon operations technology and science instruments form another highlight of present and forthcoming activities. On the other hand, small balloons are used as a test bed in the context of space missions to other planets, and some preparatory work for future campaigns for magnetospheric science and other areas of research can be noted.

The United States balloon programme, managed by NASA, continues its success in supporting the scientific research community. Balloon operations enhancement include improvements of the current capabilities and development of some new capabilities, particularly in the area of long-duration flights. The NASA balloon programme was thoroughly re-evaluated in 1995. This included an assessment of ballooning operations and scientific payload requirements. This assessment confirmed the importance of balloon investigations, both for the inherent science that can be obtained and for the technology development for future space missions.

A. Long-Duration Flights

The efforts for long-duration flights of balloons continued throughout the past year. These included improvement to the balloon system itself to reduce ballast consumption, efforts to increase telemetry range and to provide a wide recovery area for trans-oceanic and trans-continental flights.

Super-pressure balloons were supposed to be the most orthodox way to save ballast. However, because of technical difficulties, only small balloons of less than 7,500 m^3 volume carrying light payloads of about 50 kg were available. Many feasibility studies have been performed in recent years in various countries. France is implementing a campaign with about

200 small super-pressure balloons in the Antarctic area around the year 2000. The objectives of this project include studies of global motions in the stratosphere in the polar region.

In 1995, flights by the United States were conducted from five sites including Palestine, Texas; Wallops Island, Virginia; Ft. Sumner, New Mexico; Lynn Lake, Manitoba, Canada; Alice Springs, Australia; and McMurdo Station, Antarctica. Since 1990, the McMurdo site has been used annually for two long-duration flights. This past year in McMurdo a new flight duration record of almost 24 days was achieved.

The newly developed and tested NASA long-duration ballooning (LDB) non-polar LDB support system was successfully integrated with a new automated balloon pressure control system. The combined system will enable the use of pressurized balloon designs which will offset the need for ballast, thereby allowing longer flights and providing greater altitude stability. Unfortunately, the integrated system long- duration demonstration mission from Inuvik, Northwest Territories, Canada, to the Greenland Ice Cap had to be cancelled due to poor weather. This newly integrated capability will provide over-the-horizon commanding and telemetry through both the NASA TDRSS and the INMARSAT system: as well as autonomous balloon altitude control.

Test flights have demonstrated the applicability of an automated pressure control system for non-vented, over pressurized balloons as well as an automated ballast release system. Both systems are quite flexible and characteristic control parameters can be modified during long-duration missions in over-the-horizon mode.

Campaigns for long-duration flights over Antarctica in summer take advantage of continuous daylight, and therefore no, or only minor, ballasting is required. In 1995, Japan conducted test flights for the recovery of payloads near the launching site in view of extending programmes in 1996. In an Antarctic flight, the efficiency of cosmic ray observations is one order of magnitude higher than at mid-latitude. Thus, one flight exposure at Antarctica almost corresponds to the total exposure achieved in the past decade. Because of the high cost performance of this programme compared with other space programmes, it is hoped that this programme will be extended further in the future years. The Antarctica flights will undoubtedly open a new era of scientific ballooning for space exploration.

A different approach to save ballast is to control the thermal environment of the balloons to prevent the cooling of the helium gas inside the balloons after sunset. A French group has continued the project of MIR (Mongolfière Infrarouge), which constitutes a hot air balloon heated by the infrared radiation from the ground. They succeeded with a flight of 69 days in 1994 floating 1.5 times around the Earth near the equator with a payload of 60 kg. The altitude ranged from 18-30 km. A thermal cap balloon is another invention by a French group along this line. This is a helium filled balloon with a thermal insulation cap to reduce the cooling of the gas after sunset.

A Russian group carried out long-duration flights from Kamchatka to Ural lasting for 5-7 days. A new achievement in 1995 was the first collaborative observations of extremely high energy cosmic rays by the Russian and Japanese groups. Two balloons were launched from Kamchatka in July 1995 and were successfully recovered near Volsk. Another international effort involving Russia is being conducted in collaboration with China. Launches from near Beijing and recoveries of the payloads in Russia took place in the summer of 1995.

Several trans-Mediterranean flights were successfully conducted in the summer of 1995 in a cooperative programme between Italy, France and Spain. The balloons were launched from Sicily and the payloads were recovered in Spain.

B. Other Balloon Campaigns

The European Arctic Campaign was conducted successfully from 1994 to March 1995. In the campaign, called the Second European Stratospheric Arctic and Mid-latitude Experiment (SESAME), 44 balloons were launched from Kiruna, Sweden, Aire sur Adour and Gap, France, and Leon, Spain. Managed by the French, this collaboration involved various European countries including Russia. In coordinated observations from satellites, sounding rockets and ground-based experiments in the polar region, the atmospherically minor constituents such as ozone and others as well as the global motions of the atmosphere were studied.

In a joint Japan-United States programme, an experiment of a super-conductive magnetic spectrometer was performed from Lynn Lake, Canada, in 1995, following the successful flights of 1993 and 1994. Because of the large size of the super-conductive magnet (1 m diameter x 1.3 m length), 21 anti-protons were detected, an unprecedented result in this low energy region.

China, India and Brazil also performed balloon flights with scientific observations in the reporting period, and some technological progress has been made in the past year.

The subject of balloons floating in the atmospheres of other bodies in the solar system is becoming one of the most exciting items in scientific ballooning. Balloons on other planets have continuously been studied by groups in France, Japan, the Russian Federation and the United States. In 1995, a test of a capsule which will be part of the Cassini mission to Titan was successfully performed at Esrange by a French group. This proved the important role of balloons as a test bed for expensive planetary missions. An Austrian group carried out a test flight for a balloon-borne magnetometer which will be used in the Russian Mars project.

C. Balloon Materials and Structural Studies

The success rate in scientific ballooning in the past year has continued to be nearly 100 per cent. The United States, France and other countries, including China, India, Japan and the Russian Federation have been improving balloon materials, structure studies and manufacturing technologies.

It is also worth mentioning that in late 1994 the two biggest balloon manufacturing companies in the United States, Winzen and Raven, agreed to be unified, as the Raven Company, combining their technological skill.

A Japanese group has continued the structural analysis of balloons and demonstrated that a pumpkin shape is more suitable for over-pressure balloons than the zero-pressure shape. The over-pressurized balloon is now in the stage of practical application, the key point being the development of suitable and reliable systems to maintain the desired over-pressure during flight.

NASA balloon research and development has continued to make progress in several technical and operational areas. In the area of balloon structural analysis, a model for representing tension fields in the material has been developed, tested, and applied successfully to several different structural shapes. The tension field is represented through the user material definition capability of a commercial, non-linear finite element code. This code has also been used to accurately predict the failure pressure of several large science balloons under different loading conditions.

As a result of the investigation of materials to be applied for new large, long duration super pressure balloons, several types of composite films are being designed. These include non-woven, scrims, and woven materials in a variety of laminated constructions. Low temperature fracture and toughness characteristics are being identified along with uniaxial and bi-axial strength and stiffness determination. Analysis has been initiated regarding the load transfer across a seam from individual fibers through the film matrix.

The first phase of the new centralized library, designed to provide an accessible, comprehensive repository of scientific balloon technology information, has been established at the NASA Goddard Space Flight Center/Wallops Flight Facility at Wallops Island, Virginia, and is accessible via the Internet.

D. Outlook

There were several reports at the COSPAR Assembly in 1994 on possible future trans-oceanic and trans-continental flights. Among those, the United States group has prepared Arctic flights to be launched from Inuvik, Canada, to be recovered at Greenland. Unfortunately weather conditions in 1995 were exceptionally unfavourable for balloon launchings and the programme was postponed to 1996.

A flight from Wakkanai, located in northern Hokkaido, Japan, to be conducted jointly by China, Japan, Mongolia and the Russian Federation is under preparation.

Due to the nature of scientific ballooning, international collaboration in this field is indispensable. As mentioned above, a new Russian-Japanese cooperative programme was started in 1995.

There are plans, mainly championed by Russian, Austrian and Scandinavian groups, for campaigns with several small balloons in northern high latitudes with launches from Scandinavia, the Kola Peninsula and Spitzbergen in 1996 and in future years. The purpose of the investigations is to gather coordinated measurements of phenomena in the Earth's magnetosphere with satellites and ground-based observatories.

Many countries have made efforts to develop new, more capable balloon-borne detectors. Some of them were reported in the 12th ESA meeting on "Sounding Rocket and Balloon Programmes and Related Research" held at Lillehammer, Norway, in June 1995. Reports were also made during the 24th International Cosmic Ray Conference in Rome in August-September 1995.

Of particular interest was the application of differential GPS for locating balloons, developed by a French group, achieving a precision of about 10 m, and to determine the attitude of the gondola with a precision of half a degree, using four antennas.

Of further interest is the application of balloons for microgravity experiments. This was first developed by a Japanese group around 1980. The concept is to drop a capsule at high altitude where the aerodynamic drag is quite low. A German group developed a capsule with thrusters and extended the duration of microgravity up to one minute. An Italian group achieved a high quality microgravity of 10^{-9} g by using a dual capsule system in which a capsule drops inside a normal microgravity capsule.

For most science disciplines, the expectations are that the flight rate of the United States groups will remain nearly constant or decrease slightly, although a few disciplines, such as infrared astronomy, expect a modest increase. New payloads are being built to take advantage of both the LDB capability and new instrument technologies. There is a strong preference to fly the new infrared payloads in Antarctica, because of the favorable environmental conditions, e.g. low humidity and uniform surface albedo. On the other hand, for payloads not requiring these advantages, e.g. the large cosmic ray payloads, the Arctic may be preferable, because of the less stringent logistics requirements. It is currently expected that the Arctic flights may accommodate larger, more massive payloads, because of the greater likelihood that they can be recovered without disassembly. Having both an Arctic and Antarctic LDB capability is considered crucial for meeting the future demand for LDB flight requests.

The rapid changes taking place in the scientific balloon programme have resulted in a significant focus on balloon operations technology and balloon science instruments at the next COSPAR Scientific Assembly.

X. SPACE RESEARCH IN DEVELOPING COUNTRIES

A number of follow-up actions have been taken by scientists from developing countries based on the recommendations of the Panel on Space Research in Developing Countries meeting held at Hamburg, from 16-19 July 1994, on the role of developing countries in ground-based experiments in support of space observations for global and regional change studies. The proceedings of the meeting have been published as a special issue of *Advances in Space Research*, a publication of COSPAR (vol. 17, No. 8, 1996).

The South Asian Regional Research Centre (RRC) of the Global Change System for Analysis, Research and Training (START) has been set up at the National Physical Laboratory (NPL), New Delhi. START is a world encompassing system of Regional Research Networks (RRN), each of which includes a RRC and a number of Regional Research Sites (RRS). RRNs, through RRCs, are linked together to provide a global system through which scientific information is disseminated and research is organised to implement the core research projects of three major international programmes including the International Geosphere Biosphere Programme (IGBP), World Climate Research Programme (WCRP) and the Human Dimension of the Global Environmental Change Programme (HDP). The close association with the countries of scientific communities of the region helps in focusing scientific activities which are peculiar to different parts of the globe. The South Asian Regional Research Network (SAS-RRN) provides a communication link between India, Pakistan, Bangladesh, Nepal, Sri Lanka, Maldives, Bhutan and Mauritius as well as between the RRCs at New Delhi, Bangkok, Beijing and other parts of the world. The Internet connectivity of RRC with all South Asian member countries is planned to be established in phases.

EUMETSAT, established in 1986, is an international governmental organization consisting of 17 West European States. Its primary objective is to establish, maintain and exploit European systems for operational meteorological satellites. The initial system of EUMETSAT is based on the Meteosat satellite developed by ESA. EUMETSAT has now launched three operational satellites and the fourth launch is scheduled for the near future. The EUMETSAT Council has approved a proposal to provide special support to the user community in the developing countries. The first EUMETSAT User Forum in developing countries was convened in Niamey, Niger, upon the invitation of the Government of Niger with the collaboration of the African Centre for Meteorological Applications Development (ACMAD).

The Ninth International symposium on Equatorial Aeronomy was held from March 20-24, 1995 in Bali, Indonesia. The symposium discussed recent progress and future perspectives on a wide range of issues concerning equatorial aeronomy. One of the main highlights of the symposium was the presentation of preliminary results of the Guara campaign jointly conducted by INPE (The National Institute for Space Research in Brazil) and NASA which involved launching of 33 sounding rockets to study phenomena related to the electrodynamics of the ionosphere over the magnetic equator. The primary processes of interest are the equatorial electrojet current system, ionospheric bubbles leading to equatorial spread-F observed on ionograms, plasma irregularities, large-scale planetary waves, medium-scale gravity waves and turbulence in the upper atmosphere.

During 1995, the Panel on Space Research in Developing Countries continued to provide financial assistance to deserving scientists from developing countries to participate in various workshops, symposia and training programmes. A two month training programme on remote sensing was specially conducted for these scientists by Anna University, Madras, India, in July-

August 1995. A workshop on low and equatorial latitudes in the International Reference Ionosphere (IRI) was held at the National Physical Laboratory (NPL), New Delhi, in January 1995. A large number of scientists from both developing and developed countries participated in the meeting to discuss the ionospheric phenomena which are characteristic of the region and which need to be taken into account in the development of IRI models.

CONTRIBUTORS

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ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

ACMAD	African Center for Meteorological Applications Development
ADEOS	Advanced Earth Observing Satellite
ALOHA	Airborne Lidar and Observations of Hawaiian Airglow
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
ALSEP	Apollo Lunar Surface Experiments Package
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
APSG	Asia-Pacific Space Geodynamics
ARMS	Automated Retrieval Mail System
ASCA	Advanced Satellite for Cosmology and Astrophysics
ASTROMAG	A large superconducting magnet
ATSR	Along Track Scanning Radiometer
AU	Astronomical Unit
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
AXAF	Advanced X-ray Astrophysics Facility
BOREAS	Boreal Ecosystem Atmosphere Study
CANOPUS	Canadian Auroral Network for the Observation of Plasmas in the Upper Atmosphere and Space
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions
CELSS	Controlled Ecological Life Support System
CEOS	Committee on Earth Observation Satellites
CERES	Cloud and Earth's Radiant Energy System
CHAMP	A Challenging Micro-Satellite Payload for Geophysical Application and Research
CME	Coronal Mass Ejections
CNES	Centre National d'Etudes Spatiales (France)
CNET	Centre National d'Etudes des Télécommunications (France)
COBE	Cosmic Background Explorer
COSPAR	Committee on Space Research
COST	Commission on Science and Technology
CRISTA	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere
CWV	Column Water Vapour
DARA	Deutsche Agentur fuer Raumfahrtangelegenheiten (Germany)
DMA	Defense Mapping Agency (United States)
DMSP	Defense Meteorological Satellite Program
DNA	Deoxyribonucleic Acid
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
EA	Environment Agency
EISCAT	European Incoherent Scatter Facility

EOS	Earth Observing System
EPCO	Early Polar Cap Observatory
EROS	Earth Resources Observing System
ERS	European Remote Sensing (satellite)
ESA	European Space Agency
ESOC	European Space Operational Center
ETALON	Russian geodetic satellite
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EURECA	European Retrievable Carrier
EUV	Extreme Ultraviolet
EUVE	Extreme Ultraviolet Explorer
FAST	Fast Auroral Snapshot Explorer
FIRST	Far Infrared Sub-mm Telescope
FUSE	Far Ultraviolet Explorer
FY	Feng Yun satellite
GALILEO	NASA's Jupiter orbiter
GCIP	GEWEX Continental Scale International Project
GCMS	General Circulation Models
GEM	Geospace Environment Modeling
Geosat	Geodesy Satellite
GEOTAIL	Satellite to study the Earth's magnetotail
GEWEX	Global Energy and Water Cycle Experiment
GFZ	Geodetic satellite financed by GeoForschungsZentrum
GGS	Global Geoscience Study
GLI	Global Imager
GLONASS	Russian space navigation system satellite constellation
GMS	Geostationary Satellite
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GOMS	Geostationary Operational Meteorological Satellite
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
GRL	Geophysical Research Letter
GRO	Gamma-Ray Observatory
GSFC	Goddard Space Flight Center (NASA)
HDP	Human Dimension of the Global Environmental Change Program
HESI	High Energy Solar Imager
HF	High Frequency
HIRS	High Resolution Infrared Radiation Sounder
HRDI	High Resolution Doppler Imager
HRVIR	High Resolution Visual and Infrared
HST	Hubble Space Telescope
HZE	Particles of high change and high currency

IAGA	International Association of Geomagnetism and Aeronomy (IUGG)
IAMAS	International Association of Meteorology and Atmospheric Sciences (IUGG)
IASTP	Inter-Agency Solar-Terrestrial Physics Program
ICE	International Cometary Explorer
ICEC	Ice Center Environment Canada
IERS	International Earth Rotation Service
IGBP	International Geosphere Biosphere Program
IGS	International GPS Service
IITS	Improved Quality of Services in Ionospheric Telecommunication Systems Planning and Operating
ILAS	Improved Limb Atmospheric Spectrometer
IMG	Interferometric Monitor for Greenhouse Gases
IML	International Microgravity Laboratory
IMP	Interplanetary Monitoring Platform
INMARSAT	International Mobile Satellite Organization
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
INTERBALL	InterCosmos Fireball
IR	Infrared
IRI	International Reference Ionosphere
IRS	Indian Remote Sensing (satellite)
IRTS	Infrared Telescope Spectrometer
ISAS	Institute of Space and Astronautical Science (Japan)
ISEE	International Sun Earth Explorer
ISO	Infrared Space Observatory
ISSA	International Space Station
ISTP	International Solar-Terrestrial Physics Program
IUE	International Ultraviolet Explorer
IUGG	International Union of Geodesy and Geophysics
LAGEOS	Laser Geodynamic Satellite
Landsat	Land remote sensing satellite
LDB	Long Duration Ballooning
LEGRI	Low Energy Gamma-Ray Instrument
LIS	Lightning Imaging Sensor
LISS	Linear Imaging Self-scanning Sensor
LOD	Length of Day
LUNAR-A	Japanese Lunar Penetrator Mission
MA	Middle Atmosphere
MAHRSI	Middle Atmosphere High Resolution Spectrograph Investigation
MESUR	Mars Environmental SURvey
Meteosat	European Geostationary Meteorological Satellite
MF	Medium Frequency
MFEX	Micro-rover Flight Experiment
MIDEX	Medium Explorer
MIR	Russian Spacecraft

MIR	Mongolfière Infrarouge
MISETA	Multi-instrumented Studies of Equatorial Thermospheric Aeronomy
MITI	Ministry of International Trade and Industries
MLTCS	Mesosphere, Lower Thermosphere Coupling Study
MO	Mars Observer
MOPITT	Measurement of Pollution in the Troposphere
MSG	Meteosat Second Generation
MST	Mesosphere/Stratosphere/Troposphere
MT	Japanese designation for a small rocket
MTP	Meteosat Transition Program
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NEAR	Near Earth Asteroid Rendezvous
NESDIS	National Environment Satellite Data and Information Service (NOAA)
Nimbus	Weather satellite
NLC	Noctilucent Clouds
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory
NSCAT	NASA Scatterometer
NSSDC	National Space Science Data Center
NSWS	National Space Weather Service
OCTS	Ocean Color and Temperature Sensor
OLS	Operational Linescan System
PAR	Photosynthetically Active Radiation
PLANET-B	ISAS programme aimed at clarifying the structure and dynamics of the Martian upper atmosphere and its interaction with the solar wind
PMC	Polar Mesospheric Clouds
PMIRR	Pressure Modulator Infrared Radiometer
PMSE	Polar Mesospheric Summer Echo
POAM	Polar Ozone and Aerosols Measurements
POEMS	A Small Explorer mission
POLAR	NASA spacecraft to study polar magnetosphere
POLDER	Polarization and Directionality of Earth's Reflectance
PR	Precipitation Radar
PRARE	Precise Range and Range-rate Experiment
PRIME	Prediction and Retrospective Ionospheric Modelling over Europe
PSMOS	Planetary Scale Mesopause Observing System
PSRDC	Panel on Space Research in Developing Countries
PW	Precipitable Water
RAMP	Results, Applications, Modelling Phase
RIS	Retroreflector in Space
RNA	Ribonucleic Acid

ROSAT	Röntgen Satellite (German X-ray satellite)
ROSETTA	Re-scoped version of the original ESA-NASA Comet Sample Return Mission
RRC	Regional Research Center
RRN	Regional Research Networks
RRS	Regional Research Sites
SAC	Satellite de Aplicaciones Cientificas (Argentina)
SAGE	Stratospheric Aerosol and Gas Experiment
SAMPEX	Solar, Anomalous, Magnetospheric Particle Explorer
SAR	Synthetic Aperture Radar
SAS-RRN	The South Asian Regional Research Network
SBUV	Solar Backscattered Ultraviolet
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SESAME	Second European Stratospheric Arctic and Mid-latitude Experiment
SIMMS	Sea Ice Monitoring and Modelling Site
SIMURIS	Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy
SIRTF	Space Infrared Telescope Facility
SLR	Satellite Laser Ranging
SMEI	Solar Mass Ejection Imager
SMMR	Scanning Multi-channel Microwave Radiometer
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SOUSY	Sounding System
SPOT	Satellite pour l'Observation de la Terre
SSIES	Ionospheric Plasma Orbit/Scintillation Monitor
SSJ	Designation of the Space Radiation Dosimeter on the DMSP satellite
SSM/I	Special Sensor Microwave Imager
SSM/T	Special Sensor Microwave Temperature
SST	Sea Surface Temperature
SST	Space Solar Telescope
Starlette	French geodetic satellite
START	System for Analysis, Research and Training
Stella	French geodetic satellite
STEP	Solar Terrestrial Energy Program
STP	Solar-Terrestrial Physics
STS	Space Transportation System
SWAS	Submillimetre Wave Astronomy Satellite
TDRSS	Telemetry and Data Relay Satellite System
TEC	Total Electron Content
TIMED	Thermosphere/Ionosphere and Mesosphere Energetics and Dynamics
TIROS	Television and Infrared Operational Satellite
TMI	TRMM Microwave Imager
TOMS	Total Ozone Monitoring Scanner

TOPEX/POSEIDON	Oceanic Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TRACE	Transition Region and Coronal Explorer
TRMM	Tropical Rainfall Measurement Mission
TurboRogue	A spacecraft qualified, United States designed, GPS receiver
UARS	Upper Atmosphere Research Satellite
UN	United Nations
USAF	United States Air Force
USML	United States Microgravity Laboratory
USMP	United States Microgravity Payload
UV	Ultraviolet
VEGA	Venera-Galley (Russian for Venus-Halley)
VHF	Very High Frequency
VIRS	Visible Infrared Scanner
VISSR	Visible and Infrared Spin Scan Radiometer
VLBI	Very Long Base Interferometry
VMPM	Venus Multi-Probe Mission
VNIR	Visible and Near-Infrared Radiometer
VSOP	VLBI Space Observatory Program
WCRP	World Climate Research Program
WDC	World Data Center
WEFAX	Weather Encoded Facsimile Transmission
WGCV	Working Group on Calibration/Validation
WiFS	Wide Field Sensor
WIND	NASA spacecraft to study solar wind and terrestrial plasma
WIND II	Wind Imaging Interferometer
XMM	X-ray Multi-Mirror
XUV	X-ray and far Ultraviolet

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